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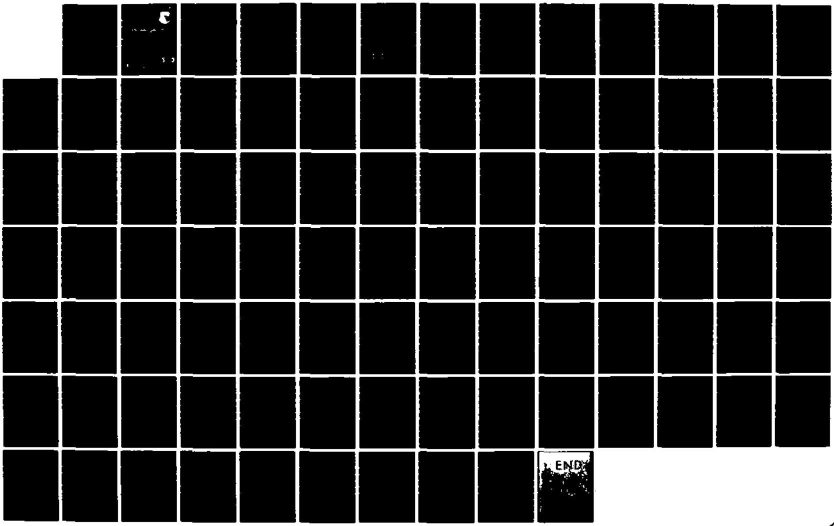

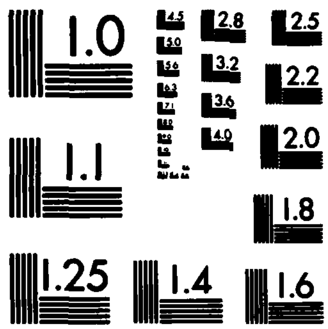

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This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 169-3.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

CHARLES BATES, JR.
Chief, Human Engineering Division
Air Force Aerospace Medical Research Laboratory

REPORT DOCUMENTATION PAGE

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The variability in night visual capacity of military aircrew may be relevant to task selection especially for the low level night operation of the light observation helicopter. The experimental objective was to assess the extent of variation in threshold for spatial frequencies and in the time to recovery of dark adaptation after a standard light exposure simulating a flare illumination. The subjects were eleven volunteers, five of whom were aircrew. After assessment of their distant visual acuity, the subjects were dark adapted for a period of thirty minutes. The level of adaptation was measured with an adapto-

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE meter which had the capability of presenting the stimulus at several spatial frequencies. A brief exposure to the simulated flare illumination was immediately followed by assessment of the effect on dark adaptation and time for recovery.

Considerable variation was demonstrated in the rate and threshold levels of dark adaptation for light and for resolution of several spatial frequencies. Following the simulated flare exposure of 0.8 mL for 90 seconds, most subjects attained a threshold level for light within 30 seconds and there was *no* evidence of a recovery effect in the curves of the threshold luminance for resolution of a 6.25 cycles per degree grating. Marked differences in the threshold levels and in the spread of the subjects' estimations were clearly evident.

PREFACE

The research described in this document was performed at the Air Force Aerospace Medical Research Laboratory, Human Engineering Division, Crew Systems Effectiveness Branch, in the Night Vision Evaluation Facility, Wright-Patterson AFB, OH, under Work Unit 7184-11-44. The original document was a thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Aerospace Medicine.

The author wishes to thank Dr. H. Lee Task and Lt Col Louis V. Genco for their assistance in hardware development and test facility usage, as well as Systems Research Laboratories personnel who assisted in data acquisition and graphing.

TABLE OF CONTENTS

I. OBJECTIVE

The aim of this investigation was to examine some individual variations in certain aspects of night vision and, in particular, to assess the effect on the threshold recovery time of eleven subjects following exposure to the ground reflected light of a simulated MK 45 aircraft parachute flare.

II. INTRODUCTION

Because of the anticipated sophistication of a future enemy's detection and weapon systems LOH (Light Observation Helicopters) deployed in the FEBA (Forward Edge of the Battle Area) in a future conflict will be operating in conditions of low visibility and will employ NOE (Nap of the Earth) flying techniques using available cover to avoid visual detection and surveillance radar. Low level night operations will play a much more significant role in any military action in the next decade than they did in the Vietnam War.

Night vision goggles have revolutionized low level night flying but night flying skills and unaided night and low visibility visual perception of the pilot and observer may be critical on and off the battle field.

Scanning techniques, night visual illusions, night disorientations can be explained to aircrew and practice will give confidence and improve night flying skills; but, it is recognized in active squadrons that a number of competent VME (Visual Meterological Conditions) and IME

(Instrument Meterological Conditions) pilots are not comfortable flying at night. Others find difficulty with some aspects of night operations, while the skills of others seem to relatively improve after dark.

Feldman[27] reported a series of dark adaptation threshold values on 75 persons arrested for serious motor vehicle accidents and found that although those with normal night vision had three times as many accidents during the day, those with abnormal thresholds had twice as many accidents at night.

A retrospective study of aircraft incidents or of relevant combat data is not possible as records are not available. Resistance from the pilot population might be expected for any visual examinations after reported incidents.

It is reasonable to assume that some of the variation noted in night flying skills, in subjective feelings towards night flying, and, in some of the flying accidents may be attributed to biological variation in night visual perception. That this hypothesis has not been tested is due in part to the difficulty of night vision testing and the lack of standards.

None of the English speaking nations currently assess night vision as part of their selection battery of medical tests. However, in a discussion paper entitled, "Potential initial aviator vision standardization among ASCC (Air Standardization Coordinating Committee) Nation", Lt. Col. J. K. Crosely,[20] after noting the technical and logistic difficulties in assessing night vision of recruits, emphasizes the mounting interest being shown in night operations on the ground, sea and air, and the need to evaluate the night vision capability.

The incidence of night blindness as presenting symptom in the general population is rare, but there are 100,000 people in the USA with retinitis pigmentosa[10] and one estimate suggests that 15% of the normal population has some difficulty in altering light sensitivity in darkness.[121] If there is any parallel with visual defects in civilian pilots, the figures are sobering. Of the 827,592 active civil airmen in the USA at the end of 1979, 350,701 required corrective lenses; 20,058 of these were known to wear contact lenses, 15,127 had failed color vision tests, 5,156 were considered monocular and 15,000 had other eye pathology.[23] The Air Force Academy experiences a loss of approximately forty-five percent of its pilot training qualified cadets between entry and graduation due principally to the progression of myopia.[33]

Civilian pilots with certain visual defects have a higher observed to expected ratio of aircraft accidents than their fellows.[22]

The literature on individual variation in night vision parameters is sparce but in the particular situations to be faced by LOH aircrew on the battlefield as well as military groups, such as SAS (Special Air Service) patrols, night vision capability may be of major significance.

If variation can be demonstrated in a function which may have direct application in the battlefield role is may provide the rationale for pilot or task selection among aircrew.

TECHNIQUES OF MEASUREMENT OF NIGHT VISION FUNCTION

There are many instruments and procedures described for estimating night vision capacity. Most may be described as psychophysical methods as a light stimulus of varying intensity, duration or size, is presented to the subject in a dark room and the subject than makes the appropriate response if he sees the stimulus.[43] The stimulus,[25,44,45,47,96] the response[16,34] or the area of the retina[37,53,79] stimulated may be varied or the time to recognize letters or shapes[21] may be the variable recorded.[15,28,52,90] Some tests are based on the different spectral sensitivities of the rods and cones.[4,110,113,121] Electrophysical methods are also used, i.e., the electroretinography[9,24,46,84,96,97] and the measurement of the visually evoked cortical potential.[30,31,48,54,57]

The three dependent variables used in most night vision investigations have been the absolute threshold of vision, the time to obtain the threshold and the time to the cone rod crossover.

III. FACTORS AFFECTING AIRCREW NIGHT VISION

Since Aubert[5] first described the phenomenon of dark adaptation, a large number of factors have been investigated whose influence on the course or end point of adaptation had been suspected.

The factors apart from disease and unusual conditions[2] may be considered in two categories: those exogenous factors in the environment which are subject to experimental control, and endogenous factors which have an individual physiological and anatomical basis and account for the biological variability.

HYPOXIA

Hypoxia seems to produce a general darkening of the visual field subjectively.[69] A clear demonstration of the effects on night vision threshold was given by McFarland and Evans[68] in 1939. They showed significant changes in the threshold values in 15 of their 20 subjects breathing an oxygen mixture such that the oxygen concentration was 15.7 percent (equivalent to an altitude of 7400 feet). At an equivalent altitude of 15,000 feet (11.7 percent oxygen) the threshold returned to the sea level value in 2 or 3 minutes after inhaling oxygen. Upon further deprivation in four subjects, the threshold rose again to the 15,000 foot level within 2 minutes.

The curves for dark adaptation obtained while breathing at diminished partial pressures of oxygen were approximately parallel to the curves at sea level. Both the rod and cone portions of the curve are affected by low oxygen concentrations.[40] Since threshold could be varied in the dark adapted subject by increasing or decreasing the partial pressure of oxygen, it suggests that the effect is mediated through nervous tissue. For a given subject, the effect of hypoxia on the threshold values was found to vary from day to day.[70]

Sheard[101] using a different procedure, was able to detect a difference in sensitivity with the subject breathing a mixture which gave a simulated altitude of 5,000 feet. Wald[114] in his experiments, showed a lowering of the average threshold at a simulated altitude of 4,000 feet although he pointed out that to 10,000 feet there was an overlap with the ground level values. McFarland[64] writing in 1969, stated that diminished night vision had been clearly demonstrated at 4,000 feet but on the graph, illustrated, Wald is credited with a data point at 4,000 feet simulated altitude. Response time to peripheral retinal stimulation is,in part,a measure of rod function and hypoxia has been shown to have a detrimental effect on response time.[55,56]

GLUCOSE

The ingestion of glucose (1 grm per kilo body weight) has been shown to counteract,to some extent, the raised threshold levels due to hypoxia at a simulated altitude of 18,000 feet[63] and 50 gms. of glucose to counteract the effects at 12,700 feet[70] within 6 to 8 minutes. Following intra-muscular injection of insulin the dark adaptation thresholds were raised and the inhalation of oxygen lowered the levels.[63,67]

There is conflicting evidence on the effect of blood sugar when the subject is breathing air at sea level. During a glucose tolerance test, the dark adaptation thresholds were raised during the second hour when the blood sugar levels were falling and in nine of ten fasting subjects, a normal breakfast was found to lower the thresholds.[63] The same author[70] later reported the results of an experiment where the dark adaptation thresholds were monitored following the ingestion of 50 gms. of glucose by a fasting subjects and he found no change in visual sensitivity. Sheard[101] reported that for his subjects, fasting for 15 or 16 hours, that breathing oxygen at ground level not only increased the speed of dark adaptation but also produced lower thresholds than those obtained when the subjects were breathing air. After the ingestion of food, the threshold levels were approximately the same or better irrespective of whether the subject was breathing air or oxygen.

CARBON MONOXIDE

McFarland[35,36,71] and his co-workers reported a series of experiments where they used four well trained subjects breathing gas mixtures while dark adapted. Their threshold levels were tested at ten minute intervals with a Crozier Holway discriminometer and thus only cone vision was involved. Carbon monoxide was introduced into the system and the amount of carbon monoxide in the blood was estimated using finger prick samples taken at 10 to 15 minute intervals. A rise in visual threshold was demonstrated following successive doses of carbon monoxide. An effect was noticeable when the Carboxy hemoglobin percentage in the blood rose from a pre-test 0·5 to 4·5. The immediate effect was approximately the same as that produced by an equivalent amount of oxygen desaturation in the arterial blood. Recovery from the effects of carbon monoxide lags behind the elimination of the gas from the blood so the effects are related to the duration of the presence of carbon monoxide in the blood as well as to its concentration.[35,36] In 1973, McFarland[66] published the results of experiments where the subjects had Carboxy hemoglobin levels of the order of 4 percent, 11 percent and 17 percent. Their dark adaptation was measured with a visual discriminometer. He was unable to demonstrate statistically significant differences in the test, pre-test results at Carboxy hemoglobin levels less than 17 percent.

Luria[59] using a night vision sensitivity test developed at the Naval Medical Research Laboratory which samples the subjects' scotopic sensitivity at a number of retinal positions, could not demonstrate that breathing 195 ppm Carbon monoxide in air for three hours (enough to raise the Carboxy hemoglobin level in the blood by approximately 10 percent) had any effect on night vision.

SMOKING

The inhalation of tobacco smoke from three cigarettes was reported to increase the visual threshold to that obtained at an equivalent altitude of 7,500 feet, and this was attributed to the influence of Carbon monoxide. In view of the evidence sited above, this seems unlikely. Constriction of the retinal vessels by nicotine may be a factor but Troemel[111] showed a facilitation of dark adaptation with nicotine. Using an automatic adaptometer and twelve subjects Calissendorff[17] was able to demonstrate only a minor impairment in dark adaptation primarily in the mesopic range. The inconsistency in these results must be resolved in terms of measuring devices, techniques and individual variations.

VITAMIN A

Following the work of Hecht and Mandelbaum,[42] it was held that a rise in the threshold of dark adaptation was a very sensitive index of dietary avitaminosis. In their study, using a Hecht Shlaer adaptometer,[43] and two subjects on a diet almost free from Vitamin A, a trend was noticable in their data after the first day of absence of Vitamin A from the diet. After 15 days, the rod threshold had risen to an extreme found in only 3 percent of the normal population examined. With a return to a balanced diet and Vitamin A supplements, the threshold remained elevated for two months.

Three facts are beyond dispute -- Vitamin A is found in mammalian retinas;[112] in some persons whose dark adaptation thresholds are high the administration of Vitamin A reduces the threshold; the threshold of dark adaptation can be raised by restricting Vitamin A in the diet. Sheard, Steffens and Beier[101] reported that their three normal subjects on a diet containing only 100 to 300 international units of Vitamin A for periods of 42, 160 and 190 days respectively, maintained less than 0.4 log unit rise in threshold for rods and cones.

There is evidence to suggest that the skin and fatty tissues are depleted slowly of their stores of Vitamin A. Both the above experiments were well controlled and used suitable apparatus but the number of subjects was small and the effects of individual variations cannot be discounted. The biophotometer was used in many studies in the late 1930's and perhaps accounted for the reported varied effects of Vitamin A on dark adaptation, for this instrument does not incorporate some of the critical specifications for measuring dark adaptation.

Case reports of patients with coeliac disease[76] defective diets, follicular hyperkeratosis, and cirrhosis of the liver[101] have shown marked rises in dark adaptation threshold levels which were lowered to normal levels after therapy with Vitamin A. Sloan[103] studied nine patients with elevated thresholds which were restored to normal levels following Vitamin A administration sometimes with the addition of Riboflavin.

It may be concluded that severe Vitamin A deficiency causes an elevation of dark adaptation threshold throughout the dark adaptation process, but this is a late manifestation of Vitamin A deficiency. Recovery is variable.

Since it has been found that the reduction in Rhodopsin concentration from Vitamin A deficiency is related to the threshold in the same manner as the photic bleaching of Rhodopsin,[24] there is little doubt of the mechanism of action of the deficiency.

AMBIENT LIGHT LEVELS AND DAY TO DAY VARIATION

Investigating the variability of dark adaptation, Wolf[119] reported that the variability in the final thresholds for rods and cones could be reduced by a factor of two, if the subject was seated in the dark for thirty minutes before the pre-adaptation light exposure. The tungsten filament lamp and lens system used for the pre-exposure gave a luminance of 1500 mL at the eye for ten minutes. Elevated final thresholds for his subjects were found to be associated with prolonged periods outdoors or driving on a clear day without sunglasses. Seasonal sunlight changes may have an effect as Kinney[53] using a stimulus recognition technique found a higher average percentage of stimuli identified in the winter months.

Mote[74] could not find any day or seasonal factors which were a significant source of variation in the final threshold values obtained on his two subjects after a pre-adaptation exposure intensity of 1244 mL for two minutes. The examinations were repeated over a period of eleven months. In particular, there was no association between forenoon and afternoon recordings but the influence of factors in the early phase of rod adaptation could not be determined because of day to day variability. No seasonal changes were evident over the eleven month period. Craik[19] found that daily variations in the dark adaptation curve could be reduced to a range of 0.2 log units by a pre-adaptation exposure to .22 equivalent foot candles viewed for three minutes. Hecht and Mendelbaum[42] found a maximum day to day variation in threshold of 0.3 log unite micromicrolamberts following pre-adaptation exposure to 1500 millilamberts for three minutes. Sheard,[101] also found a 0.3 log unit variation in threshold from day to day. There is little change in the threshold levels over a period of ninety minutes after adaptation.[92]

Pre-adaptation exposure to ultraviolet light is followed by a later onset of rod adaptation and a higher final threshold.[100,118]

EXERCISE

In a study of four long distance runners under controlled laboratory conditions using the Hecht Shlaer adaptometer, Jones and Wilcott[51] reported elevation of the dark adaptation threshold during moderate exercise (pulse rate 100-120 beats per minute). This was particularly marked in the inferior visual fields. The elevation of two or more log units occurred during the first 20 minutes and was sustained throughout the period of exercise. They hypothesized that the decrement may be due to the lack of increased ophthalmic artery pressure during exercise and changes due to cerebral auto regulation reducing the blood flow to the retina.

ACID BASE BALANCE

Wald[114] and his co-workers investigating the effects of respiratory acid base imbalance on dark adaptation threshold found that an increase in the rate of breathing room air could decrease the threshold by 0.12 to 0.41 log units in 5 to 10 minutes. On return to the normal rate of breathing, the threshold rose again in 2 or 3 minutes. The increase in sensitivity can be abolished by adding 2 percent Carbon dioxide to the inspired gas. When acidosis was induced by gas mixtures containing 5 percent Carbon dioxide, the threshold levels rose 0.2 to 0.5 log units both for normal and rapid ventilation.

The hyperventilation accompanying anxiety may improve the subject's threshold levels.

DRUGS

Of the drugs which have been shown to affect night vision, few lower the dark adaptation threshold. Thyroid extract or Alpha dinitrophenol given to three patients with cirrhosis of the liver or rheumatoid arthritis apparently lowered the dark adaptation threshold.[80] In a similar manner, Vitamin A administration has been observed to lower the threshold in cases of Vitamin A deficiency. There are no available reports which show a prolonged lowering of the threshold in healthy males after drug administration.

Individual metabolic differences account for a number of drug toxic effects on the visual apparatus. Drugs which interfere with oxygen transport or utilization adversely affect visual sensitivity. The phenothiazines can block Rhodopsin synthesis and Halothane interferes with pigment regeneration.

Of the drugs which pilots are likely to ingest, Alcohol has been shown to have a detrimental effect on threshold values;[27] Acetyl salicylic acid appears to have no significant practical effect on dark adaptation; Dimenhydinate significantly degrades night vision.[60]

AGE

There is general agreement on the detrimental effect of aging [6,15,77] on night vision. Hecht and Mandelbaum[42] found that the greatest effect of aging on dark adaptation was on the cone threshold but they did describe a subtle shift in rod thresholds as age increased. Robertson and Yudkin[91] using different apparatus reported a significant correlation coefficient between age and final rod threshold of 0.56 and that the range of variation in rod threshold increased with age, e.g. between 20 and 30 ages it was 1.1 log units and between 50 to 60 it was 1.45 log units.

McFarland and Fisher[62] studied 201 subjects using the Hecht-Shlaer apparatus and described a consistent decline in ability to see at low levels of illumination with increasing age. They were able to predict the final threshold using age and a correlation coefficient of 0.89. In their series,an increase of 13 years in age corresponded to a multiple of 2 in the intensity of illumination necessary at threshold. As the Hecht-Shlaer apparatus uses an artificial pupil, it seems unlikely that the deviation of the pupil size with age can account for the deterioration noted as was suggested by Robertson and Yudkin. It seems more likely that the effect is neurological. Zuege and Drance[120] reported that thresholds increased with age particularly after 40 years of age, and their measurements were corrected for a 7 mm standard pupil, also that most rod adaptation occurred in 20 minutes in the under 50 age group and that the process was almost complete in 25 minutes where as,in the older group,it continued through 30 minutes.

RACE

A comparison of the dark adaptation of 16 white and 12 black subjects showed no significant differences between the two groups.[82]

SEX

Sex differences in the rate or threshold of dark adaptation have not been found in any large series,[15,26,42,91] but in some experiments with few subjects differences have been noted,[89] and Feldman[27] reported that in his experience the threshold is higher in women. In a series designed to demonstrate any sex differences in the visual modality, McGuinness[72] was unable to show any significant difference in threshold measurements. In 1978[7] a significant increase in scotopic threshold was reported in six women on the day of ovulation. It was suggested that the peak values of Oestriol, luteinising hormone and

Vitamin A which coincide with ovulation may be related to the observed increase in sensitivity.

PSYCHOLOGICAL FACTORS

Well motivated subjects perform well. Confidence is engendered by training programs and practice although there is little positive evidence to vouch for the improvement in night vision following training. Scano[98] found statistically significant better adaptation in a group of 35 military aircraft pilots than in a control group of 30 non-pilots. Training motivation or both may account for this apparent occupational difference.

IV. NORMAL NIGHT VISION

The difficulty in making reproducable measurements of night visual capacity is evidenced by the multiplicity of procedures which have been employed. For meaningful estimates of threshold which are comparable between individuals, a number of variables must be controlled in the apparatus and technique.

(a) Pre-adaptation Stimulus

The effects of prior ambient light levels have been discussed. That the course of dark adaptation varies with the pre-adaptation light intensity was established by Hecht in 1937. Pre-adaptation intensities below 200 photons were followed only by rod adaptation and intensities above 4,000 photons were followed first by cone adaptation and then by rod adaptation. Rapid rod adaptation was evident after pre-adaptation to low intensities and delayed rod adaptation followed high intensity pre-adaptation stimulation.[38] These findings were further elaborated by Mote.[75] His results showed that if the pre-adaptation intensity was increased at constant duration or the duration was extended at constant intensity, the initial threshold rose and dark adaptation was prolonged. However, he found that a given increase in intensity exerts more effect than a corresponding increase in duration. At lower intensities of pre-adaptation, colored stimuli are seen at lower threshold values.

Dark adaptation is much faster following red light pre-adaptation and it may be 30 times as bright as a white light and be followed by the same speed of dark adaptation.[41] The value of red light in pilot ready rooms was demonstrated by work at the Air Force School of Aviation Medicine.[93] An exposure time to red light of 3.5 to 5 minutes was found to result in the most effective adaptation.[81] Hulburt[49] also demonstrated the advantage of red illumination for dark adaptation. A dominant wavelength of 626 mμ resulted in the most rapid adaptation and the maximum difference between threshold levels obtained following exposure to light having a dominant wavelength of 626 mμ and neutral (white) was 0.5 log μμL.[93] Connors[18] some years later determined that after one minute of adaptation to light of 610 mμ recovery was faster than after exposure to an equally bright light of 595 mμ, but after 5 minutes of exposure recovery time was progressively shortened by lengthening the wave length to 640 mμ. Beyond 640 mμ lengthening the wave length resulted in no meaningful increase in scotopic sensitivity. These advantages of red light for dark adaptation are predictable from the luminosity curves of scotopic and photopic vision.

SIZE, WAVELENGTH AND DURATION OF THE TEST STIMULUS

As the visual system is capable of spatial summation over a limited time interval, the larger the test field used in a threshold measurement, the lower will be the threshold luminance. (For constant energy in a test flash luminance and area are reciprocally related within the limits of complete spatial summation. However, spatial summation capability appears to change during the course of dark adaptation).[85] Different test light wavelengths can give different forms of the dark adaptation curve.[14] With red light as the test stimulus there may be no rod branch evident in a dark adaptation curve and if blue light is used, the rod branch will fall to the lowest threshold level. Within the time interval for spatial summation by the visual system luminance and flash duration are reciprocally related up to a critical duration which is longer in the dark adapted eye. If the flash duration exceeds the critical duration, the threshold energy and the dark adaptation curve may be altered.[85]

LOCATION OF THE TEST ON THE RETINA

Hecht[39] determined that the observed differences in dark adaptation for centrally and peripherally located fields were related to real changes in sensitivity. Riopelle[89] was able to plot contours of equal sensitivity of the retina for the dark adapted eye. He found maximum sensitivity on either side of the fovea on a horizontal meridian 20^{o}-30^{o} eccentrically. Experiments by Sloan[102] and Zuege[120] support this view.

SIZE OF THE PUPIL

The pupil is capable of changes in diameter by a factor of 5 or 6 and this is associated with a change in retinal illumination by a factor of 20 approximately. This must be taken into account during threshold measurements. Sloan[102] computed a correction factor in log units to compensate for the reduction in the amount of light reaching the retina due to a decrease in the effective diameter of the pupil with distance from the axis of fixation.

NORMAL THRESHOLD

Having regard for the many environmental, physiological and psychological influences described and the limitations of the apparatus and technique for measuring dark adaptation, it is no surprise that there is considerable variability in the threshold values even in large series.

In the frequently referenced work of Hecht and Mandelbaum[42] using a Hecht Shlaer adaptometer, a pre-adaptation exposure level of 1,500 millilamberts and a field occupying 35 degrees of visual angle for three minutes, the authors plotted the course of dark adaptation in 110 subjects drawn from a university population. They found the range to be approximately 4 log units and a total spread of the final rod thresholds to be 1.0 log units (0.3 log unit was held to be the expected day to day variation) about a mean of approximately 1,000 micromicrolamberts.

Using a group of 45 airline pilots, Sheard[101] found a variation of 0.5 to 0.7 log units about a mean of 100,000 micromicrolamberts.

Sloan[103] assessed normal variation in 101 subjects ranging in age from 14 to 70 years. The mean log threshold (micromicrolamberts) at 19 different retinal locations was 4.41 with a standard deviation of 0.25 log units.

McFarland and Fisher[62] using the Hecht and Shlaer apparatus and technique with 201 subjects between 20 and 60 years of age, found a final threshold mean of 2.92 log unit micromicrolamberts and a standard deviation of .09 log units. These figures are in close agreement with those of Hecht.

The effects of age on threshold have been discussed previously.

USEFUL INDICES OF NIGHT VISION

Although the flare of a single match on a moonless, overcast night on some occasion may have alerted the watchful observer to the presence of the enemy, such operational circumstances are rare and there is little face validity for aircrew in the determination of threshold values by the methods of Hecht, Sloan and others. The night sky brightness is such that even with unbroken dense overcast and precipitation the normal adapted naked eye can see a hand in front of the face.[73]

Pilots use both eyes for observation, the size of their pupils is not fixed, the exposure times are greater than a few milliseconds, they use as much of their retina as they can and they use their training to look around the target. Perception for them depends on a combination of motivation, stress, experience, training, decision making and physiology.

Studies have been undertaken that use a more operationally related task. El Hay[26] examined the night vision sensitivity of 1165 normal Egyptian males and 50 females drawn from aircrew and hospital attendants of the Egyptian Air Froce. He used a device which recorded the time taken for the subject to perceive certain geometric shapes while in the dark following exposure to a pre-adaptation standardized light for two minutes. The range of values they obtained was 10 to 55 seconds with an average of 34 seconds.

This test is similar to that used by Burg[15] to measure glare recovery time, where the time of identification of a shape at a predetermined light level following exposure to 3.2 foot candle illuminance measured at the subject's eyes, ranged from 3.5 to 8 seconds.

As performance of a task involving visual perception must depend to some extent on the visual receptors stimulated, reaction time to light stimulation while the subject is dark adapted is a measure which involves night vision. This has been investigated[8] and in general, the reaction time to scotopic flashes presented to the dark adapted subject decrease as the retinal location of the stimulus moves into areas where there are fewer cones and more rods[117] as described by Osterberg,[78] although,in an earlier series it seemed that reaction times to peripheral stimulation were shorter[58] in the dark adapted subjects.

V. EXPERIMENTAL PLAN

To achieve some degree of face validity, in this experiment the apparatus and experimental design are chosen to mirror a combat situation as in the scenario previously described. During periods of medium to high activity in the FEBA, it may be predicted that the area will be illuminated by the reflection of search lights directed at the cloud cover. If meterological conditions permit, this may give a fairly constant degree of illumination over a wide area. An alternative method involves the use of the parachute flare dropped from the air or fired from the ground. These may burn for a variable length of time from 137 to 324 seconds.[61] They may be dropped in a regular time sequence, or in groups,or they may be fired sporadically depending on the primary purpose of the illumination. For the helicopter pilot's night vision brilliant illumination of the flare followed by a period of darkness as it is extinguished may have a devastating effect. The visual field may be flooded with light of high intensity without warning and, although pilots and observers are trained to turn the aircraft away from the flare, shut one eye, cover one eye with an eye patch or use red filtered goggles to preserve some night adaptation, some will be lost in this situation,and a number of pilots find these actions disorientating. One of the most critical tasks an observer may have to perform is to read a cockpit instrument and differentiate markings at a definite spatial frequency at the very low level of instrument lighting necessary to escape visual detection at night at low altitude. In a survey of the cockpit visual problems of senior pilots, almost fifty percent admitted to difficulty reading instruments at night.[116]

The instrument lighting can be adjusted simply with a rotation switch.

HUD (Head up displays) are likely to be a feature in the next generation of LOH as is electroluminescent instrument lighting.

The procedure used simulates in part, the battlefield condition -- the dark adapted subject watches a HUD lens and is able to adjust the intensity of a square wave electroluminescent light source whose spatial frequency may be equated to that of the markings on standard engine instrument.

The resolution of various gratings has been used as a threshold criterion for dark adaptation.[11] The fovea is specialized for high acuity and must therefore handle all information about high spatial frequencies.[3] It has been postulated that visual channels exist which handle information about bands of spatial frequency. In the retinal periphery only low frequency channels are represented. When the visual angle subtended by the grating is less than approximately 5 minutes of arc rods can no longer make a significant contribution, although the relationship between the functions of rods and cones is not simple.

Stabell and Stabell investigating color threshold in scotopic and photopic vision, provided evidence of a complex interrelationship.[105, 106,107,108] After a threshold reading is taken, the subject observes a colored woodland scene which is suddenly projected on the screen in front of him. In the actual flying situation color is observed during a flare burn depending on atmospheric conditions, flare height and distance from impact point. After the light is extinguished, the threshold measurement is repeated.

MATERIALS

Apparatus was required for two tasks - firstly to provide a suitable stimulus and a method of recording the response and secondly to produce a visual field of specified luminance for the required time interval.

The stimulus was produced from an electroluminescent plate connected through a Variac voltage modulator to a source of power. The luminance of the stimulus could be calculated from the voltage. The calibration curve was derived by using a photometer and plotting voltage against luminance. A neutral density filter N.D. 2 placed in front of the electroluminescent source then allowed calibration to the required sensitivity.

Light from the electroluminescent plate rear illuminated a square wave grating with 100 per cent contrast. By rotation of a large disc holding six different gratings square waves of spatial frequency 1, 1.5, 6.25, 10, 12.5, cycles per degree visual angle could be produced.

The grating was placed at the focus of the convex lens system of a head up display. The size of the grating was such that the lens produced an image subtending $8^{\circ} \times 8^{\circ}$ with respect to the eye. On viewing the light from the lens, the fovea and the peripheral retina were stimulated.

The spatial frequency of the light stimulus could be selected by rotating the disc and the luminance could be varied with the voltage regulator. On depression of a key an electronic device automatically recorded the voltage and the time.

The apparatus to simulate the visual field following ignition of a Parachute, Attack or Briteye flare consisted of a 35mm slide projector with an incandescent bulb and a color photographic negative of a woodland scene which could be projected onto a screen. The scene was typical of that seen from a helicopter at low level in wooded country. A shutter controlled by an automatic timing device allowed the screen to be illuminated for a specified time interval (90 seconds). An average luminance 0.8 ftL was chosen for the image which was 25" x 36" cast on the screen 90" from the subject. This equates to the luminance of the target area illuminated by an MK45 parachute flare burning at 1,500 feet above the target. Ninety seconds was chosen as the exposure time as this is approximately half the burn time of the flare.

SUBJECT

The ages and sex of the eleven subjects are listed. None were smokers, some wore contact lenses or spectacles but the distant visual acuity of each subject was 20/20 with their corrective lenses. Five of the subjects were aircrew. None had had prolonged exposure to bright conditions on the day of the experiment.

Subject Number	Age	Sex	Corrective lenses	Aircrew
1	39	Male	Yes	Yes
2	30	Male	No	Yes
3	45	Male	No	Yes
4	29	Male	No	Yes
5	22	Female	No	No
6	47	Male	Yes	Yes
7	27	Male	No	No
8	33	Female	Yes	No
9	Data was not recorded			
10	20	Male	No	No
11	23	Male	Yes	No
12	21	Female	Yes	No

This sample was not random as the subjects were selected on the grounds of their availability at the Aeromedical Research Laboratory, but there was no reason to suspect that the night visual capacity of this group would be inferior to a random sample's capacity.

PROCEDURE

The apparatus was demonstrated to the subject. During the 10 minute period of instruction and familiarization, the subject sat facing a white wall of average luminance 40 ftL. The task was explained as follows: "Watch the display lens. The room will be darkened and you will be asked at intervals to turn up the light. You will then turn the luminance control knob until you can just see the light. Do not adjust the luminance by turning the knob back and forth. When you consider the light is just barely visable, press the lever of the recorder. Turn back the luminance to zero and wait for the next signal. You will make approximately seventy judgments during this phase."

The grating giving a spatial frequency of one cycle per degree was used during this first phase. The dark adaptation curves for each subject were plotted.

The instructions for the subject for the second phase were: "You will see black lines on the plate visible through the lens. Adjust the luminance as before until you can just distinguish the black lines and the pattern. Press the lever to record your judgment and return the luminance to zero as before. This will be repeated in your own time twenty-five times - five times for each of five patterns." The disc was rotated to a new spatial frequency after each set of five trials in the order 1, 1.6, 6.25,10, 12.5. Base line luminance values for each spatial frequency were obtained.

The subject was then told "Watch your front and keep your eyes open. When the scene appears search it carefully for the whole time it is visible. After 90 seconds the projector will be turned off and you will then record when you can just see the light and then when you can make out the pattern. Return the luminance to zero and repeat the two recordings in your own time, but do not pause. You will do this for three minutes and there will be five trials."

In this manner, curves were drawn for the dark adaptation recovery phase for each subject for the 6.25 spatial frequency threshold and for the light stimulus itself.

VI. RESULTS

The data is graphed in Appendix I.

1. Although the graphs of dark adaptation approximate curves

which become asymptotic to the x axis before thirty minutes have elapsed, there was too much noise in the system to allow acceptable fitting of curves to the data. On inspection there is obvious variability in the initial slopes of the curves e.g. Subject 3 attained his threshold level of approximately 1×10^{-6} ftL within 5 minutes, whereas Subject 12 required 15 minutes to attain his threshold at approximately the same level. The threshold levels varied between subjects from 2×10^{-6} ftL to 5×10^{-7} ftL.

2. The mean values of luminance threshold for resolution of each spatial frequency vary as much as an order of magnitude between subjects: Resolution of the 6.25 cycles per degree grating required an average luminance level of 0.0006 ftL for Subject 3 but .006 ftL for Subject 8. The respective standard deviations are 0.00012 and 0.0013.

3. Following the simulated flare exposure, Subjects 1, 3, 4, and 10 showed some evidence of recovery to a threshold level for the light in the first 30 seconds. The graphs of subjects 2, 5, 7, 8, 11, and 12 approximate a straight line parallel to the x axis following the initial reading after the exposure.

4. For most subjects, the threshold levels achieved during the three minute period following the light exposure are higher than the threshold levels following their initial dark adaptation.

5. There is no evidence to suggest that the threshold level for resolution of the 6.25 cycles per degree grating is decreasing following the initial reading after the exposure.

6. Most subjects maintained a similar threshold level of resolution of the 6.25 cycles per degree grating after the exposure as

they had attained during phase two of the experiment. Subject 4 selected a much higher luminance after the light exposure.

7. The after light exposure data from Subject 6 shows wide variation between selections of luminance level both for the light threshold and for the grating threshold.

VII. DISCUSSION

Direct comparison of these dark adaptation curves with those from the classical work of Hecht and McFarland is not possible due to the difference in apparatus and technique. The pre-adaptation light exposure to 40 ftL is many times less than the standard exposure to 1,500 millilamberts. This low level of exposure should be followed by an early cone-rod break. The rods may begin to adapt in five minutes.[95] In these curves the cone-rod break is not clearly defined but the stimulus is not a one-fifth second flash from the extreme violet end of the spectrum occupying 3 degrees visual angle. Nor, is the test field viewed 7 degrees nasally with the right eye. Both eyes were used, and the 8 degree by 8 degree white light stimulus ensured that some of the light would fall on the para-foveal area. The exposure time was varied by the subject.

Age, sex, corrective lenses and flying status did not appear to influence any of the findings in this small series.

The threshold levels obtained after 30 minutes dark adaptation are of the same order as those obtained by Hecht and others.

Low luminances provide low degrees of acuity and high luminances, high degrees of acuity. The thresholds for the gratings rank in order on the ordinate. The increase in the threshold levels for all subjects between the 1.5 and the 6.2 cycles per degree probably denotes a change from primarily rod function to cone function.

Brown Graham and Leibowitz[13] using a modification of the Hecht Shlaer apparatus, found in their two subjects that the luminance threshold for a 7.5 cycles per degree grating fell between .1 and .01 millilamberts but again, it is difficult to compare results across techniques.

That the exposure to a luminance of 0.8 foot lamberts for 90 seconds has a relatively minor effect on dark adaptation and that recovery occurs in most cases in less than three minutes is not unexpected. In the two anatomically distinct receptors which contain the visual pigments, three classes of cones have been identified on the basis of mean absorbance spectrum.[12] Photic exposure alters the concentration of the visual pigment and when the isomerising exposure is intense the photosensitivity of the pigments may be decreased.[115] Rod dark adaptation after a brief flash of bright light and a quantumequivelent 30 second bleach are the same.[1,83] This is 'Rushtons' paradox. A partial bleach with a light exposure of 4.55 log scotopic trolands over a 190 second period was followed by a shorter time to obtain the rod threshold level than that following a full bleach or a 1/1,500 second xenon flash. If the bleaching is small, the rod dark adaptation curves return more rapidly to the threshold levels.[94,97]

At durations of light exposure greater than 0.1 seconds it appears that total flux is the best predictor of recovery time when single pulses of exposure are considered.[29]

Johnson[50] and others investigating the effect of luminance of a CRT display on the dark adaptation of helicopter pilots found that detrimental effects on night vision were evident but minimal when the highlight luminance of the display was 0.2 fL as set by the experimenter or 0.033 fL as set by the pilot subjects. Complete recovery to the previous moonlight level (highlight luminance set at 0.01 foot-lamberts) occurred within two minutes.

The fact that the post exposure threshold readings for the gratings are above the previous levels may be an effect of the exposure and it is intended to repeat this experiment and to observe the course of the threshold luminances over an extended time period.

One of the most interesting observations made from this series is wide variation in the threshold estimations following the light exposure of Subject 6. His results stand out from those of his fellow subjects. It is probably coincidental that he is a 47 year old pilot who wears contact lenses and is currently flying fighter aircraft. It is tempting to suggest that the light exposure had a greater effect on this subject,and the experiment should be repeated as this may be simply due to the technique.

Another finding that is worth comment is the large difference noted in Subject 4 between his threshold luminance level for the 6.25 cycles per degree grating before and after the light exposure. This subject is a navigator on a high performance aircraft and he may have a higher standard of clear definition than the other subjects.

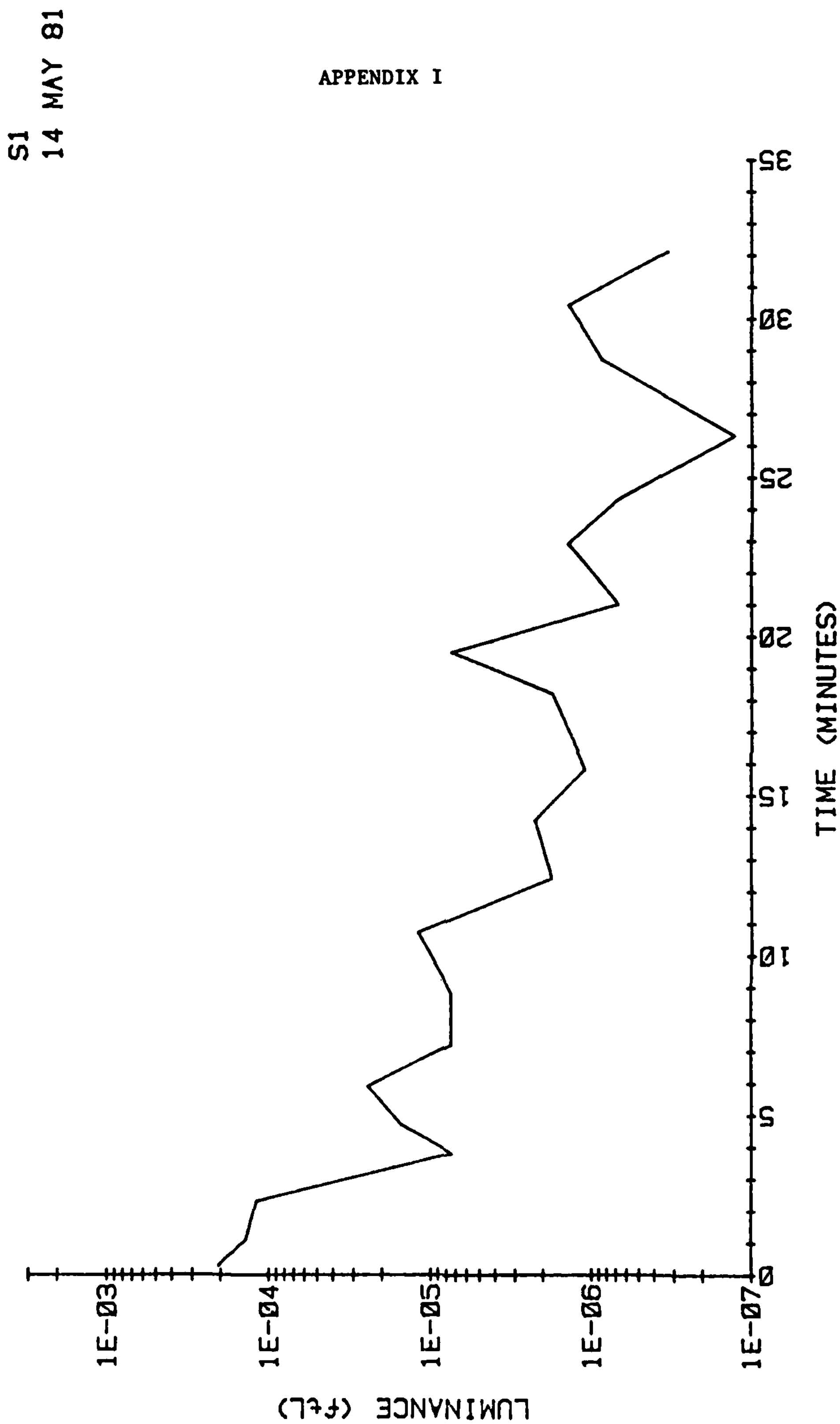
VIII. CONCLUSION

It is easy to postulate that the pilot with the most rapid dark adaptation, who has the greatest sensitivity, who has the lowest resolution thresholds of spatial frequency gratings, and who recovers most quickly to his threshold levels after light exposure would have some advantage over his adversaries on the battle field.

This experiment has examined only a few of the parameters of night vision. Some phenomena such as night myopia[87,88] illusions[109] or functions such as contrast sensitivity[86,32] may be of more significance to night flying performance.

That substantial variability exists has been shown even in this small group. Much further work is required to determine the extent of the variability and it is yet another problem to assess the relevance of this variability in helicopter aircrew.

APPENDIX I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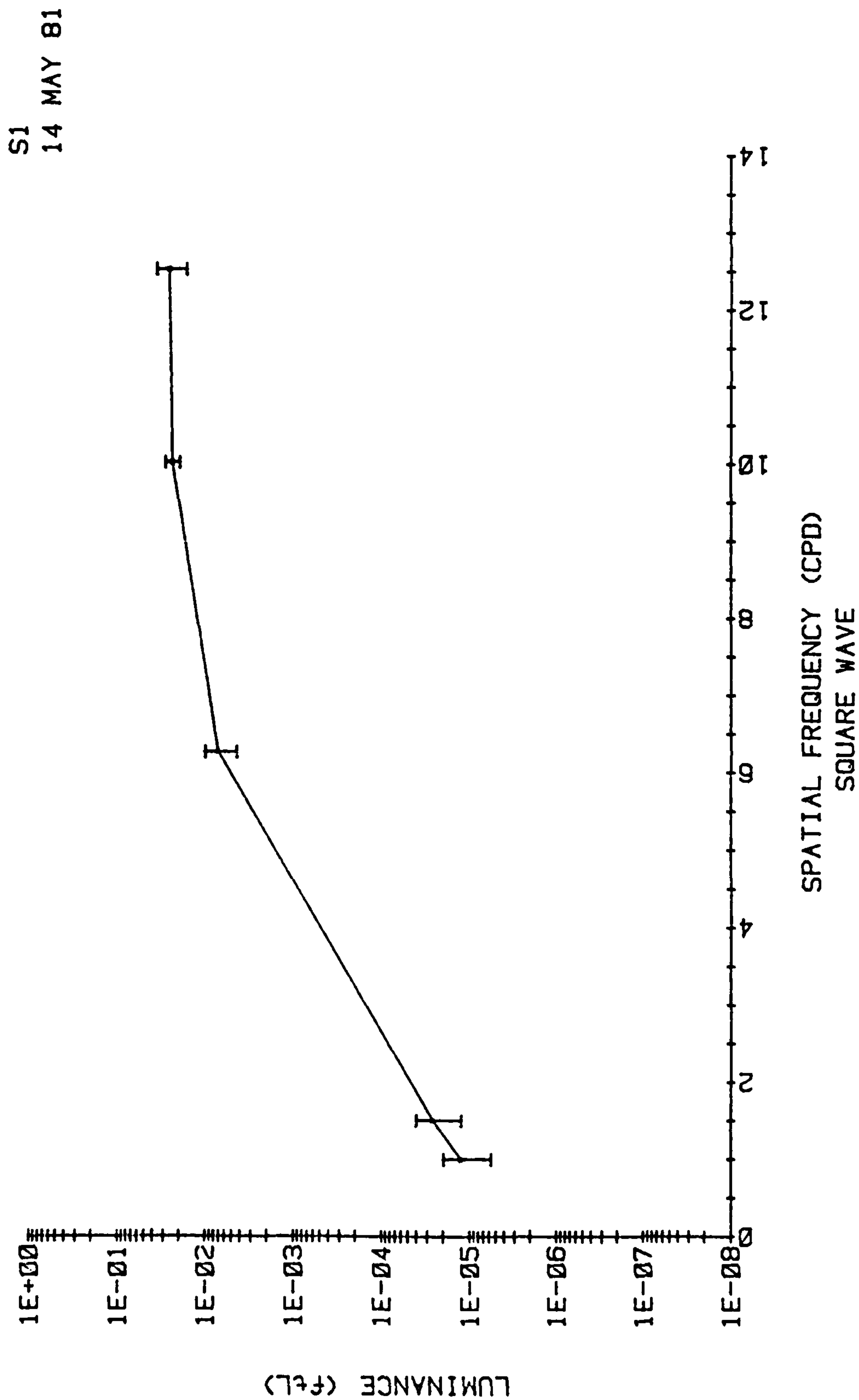
10
15
20
25
30
35



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1E-03
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1E-05
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1E-08
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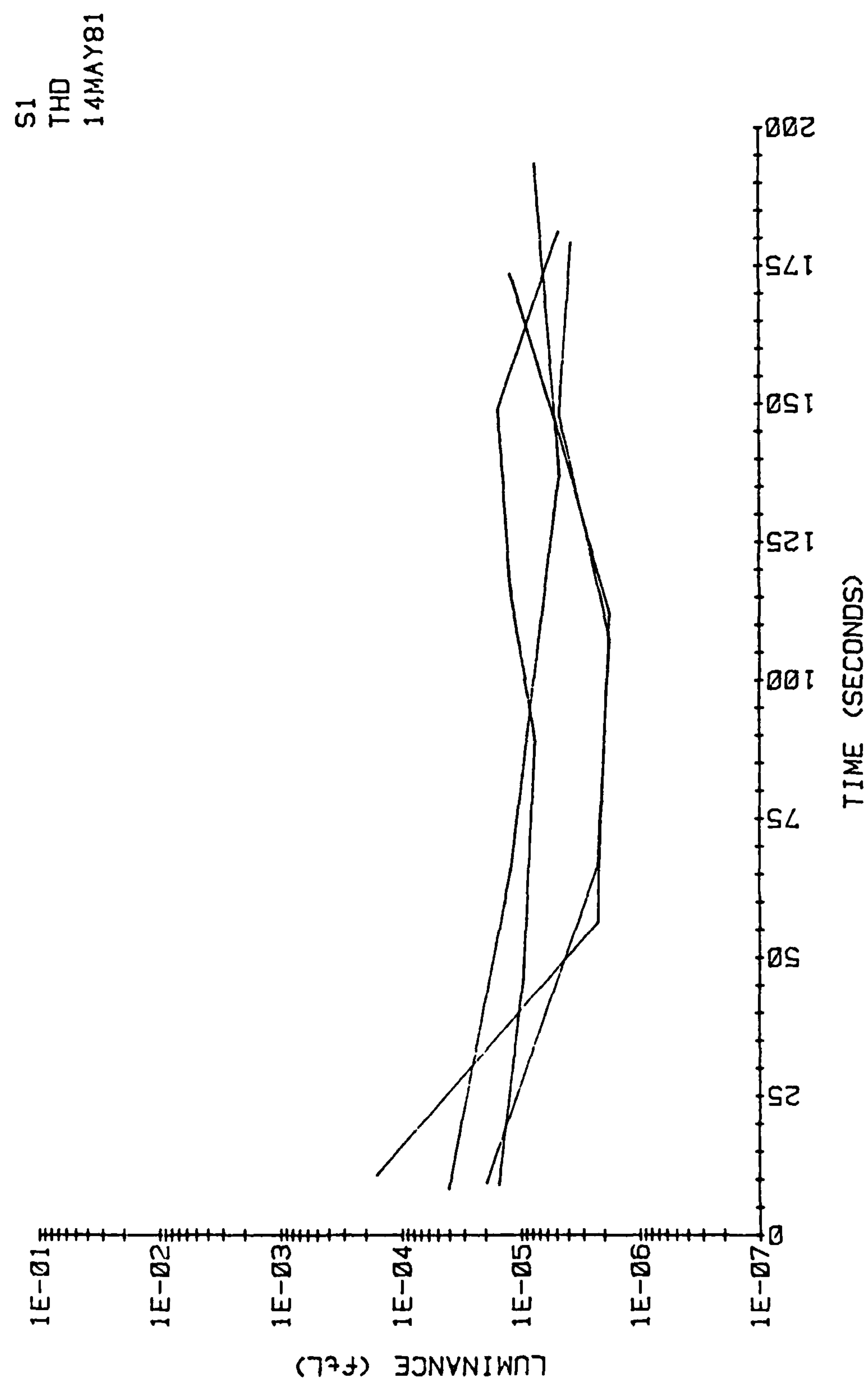
2
4
6
8
10
12
14
SPATIAL FREQUENCY (CPD)
SQUARE WAVE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1E-07
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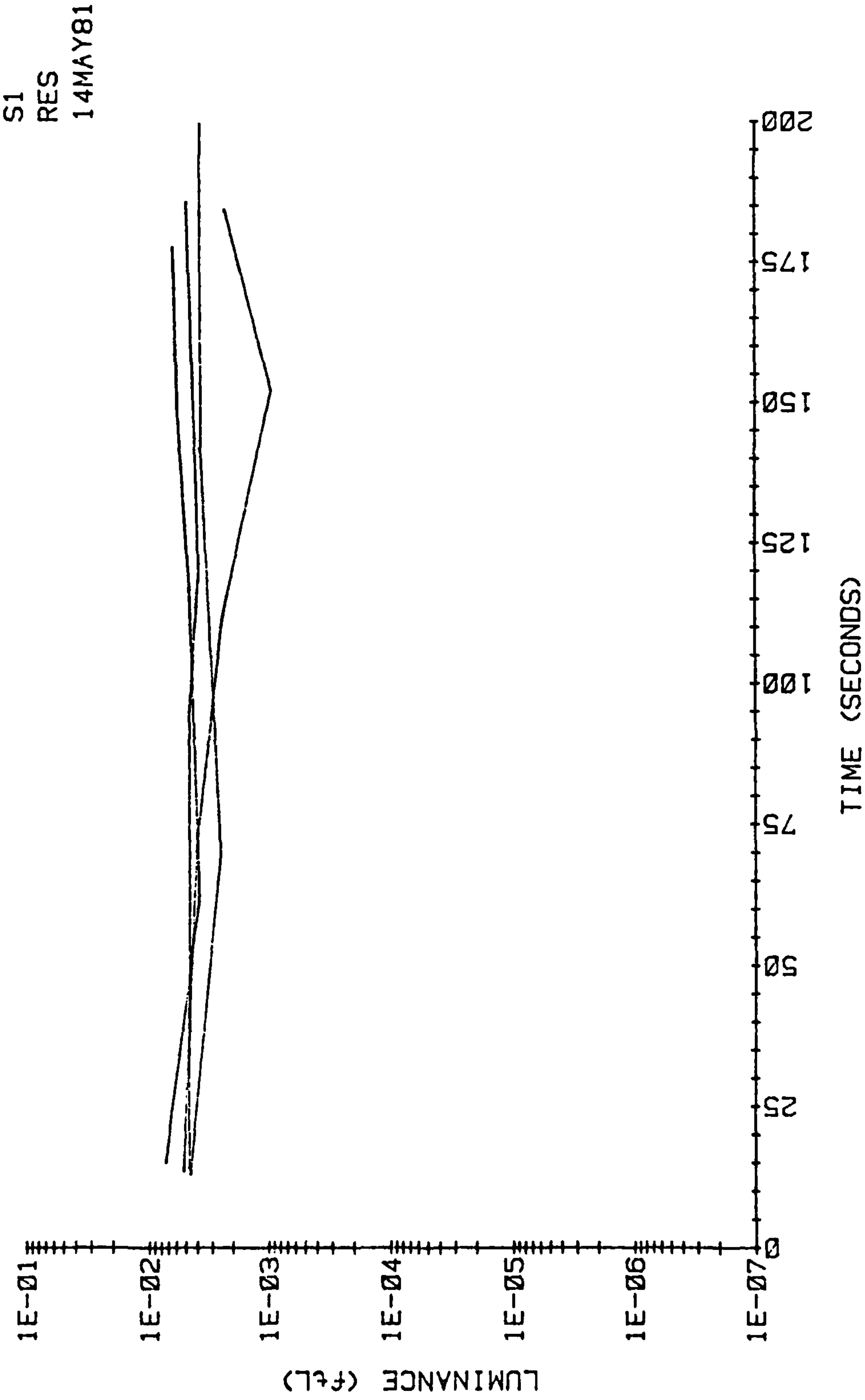
75
100
125
150
175
200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RES
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TIME (SECONDS)
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75
100
125
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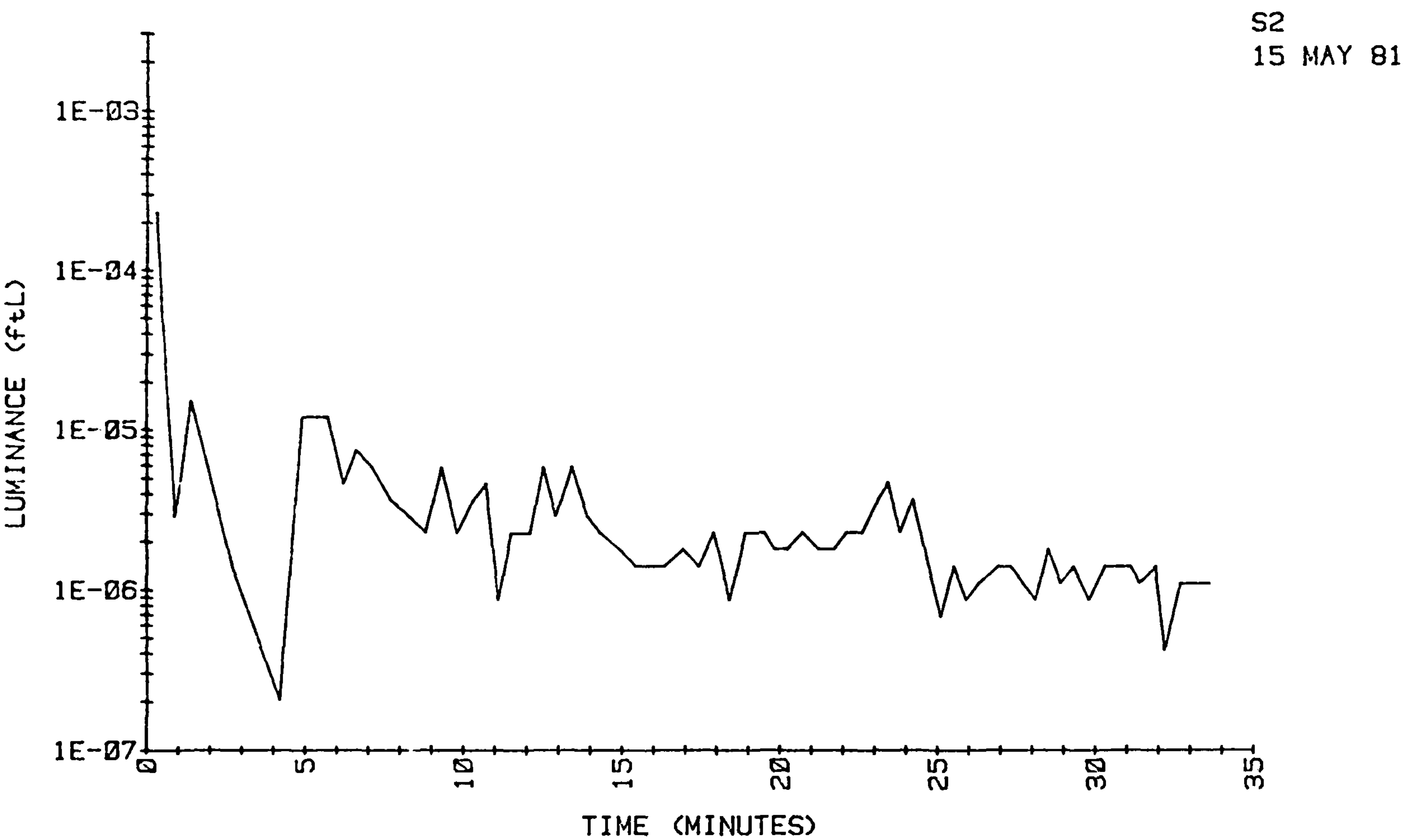
1E-03
1E-04
1E-05
1E-06
1E-07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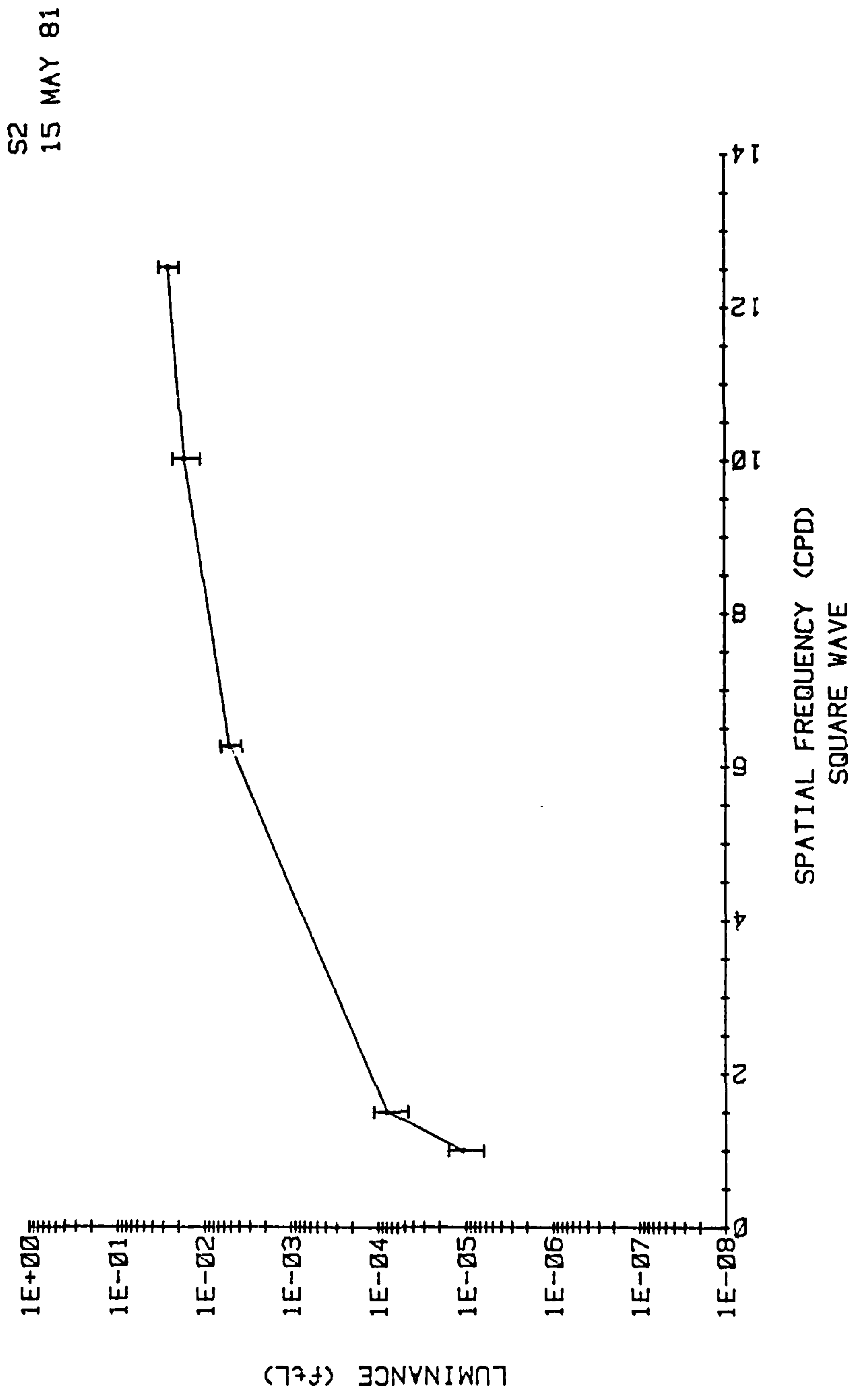
15
20
25
30
35
TIME (MINUTES)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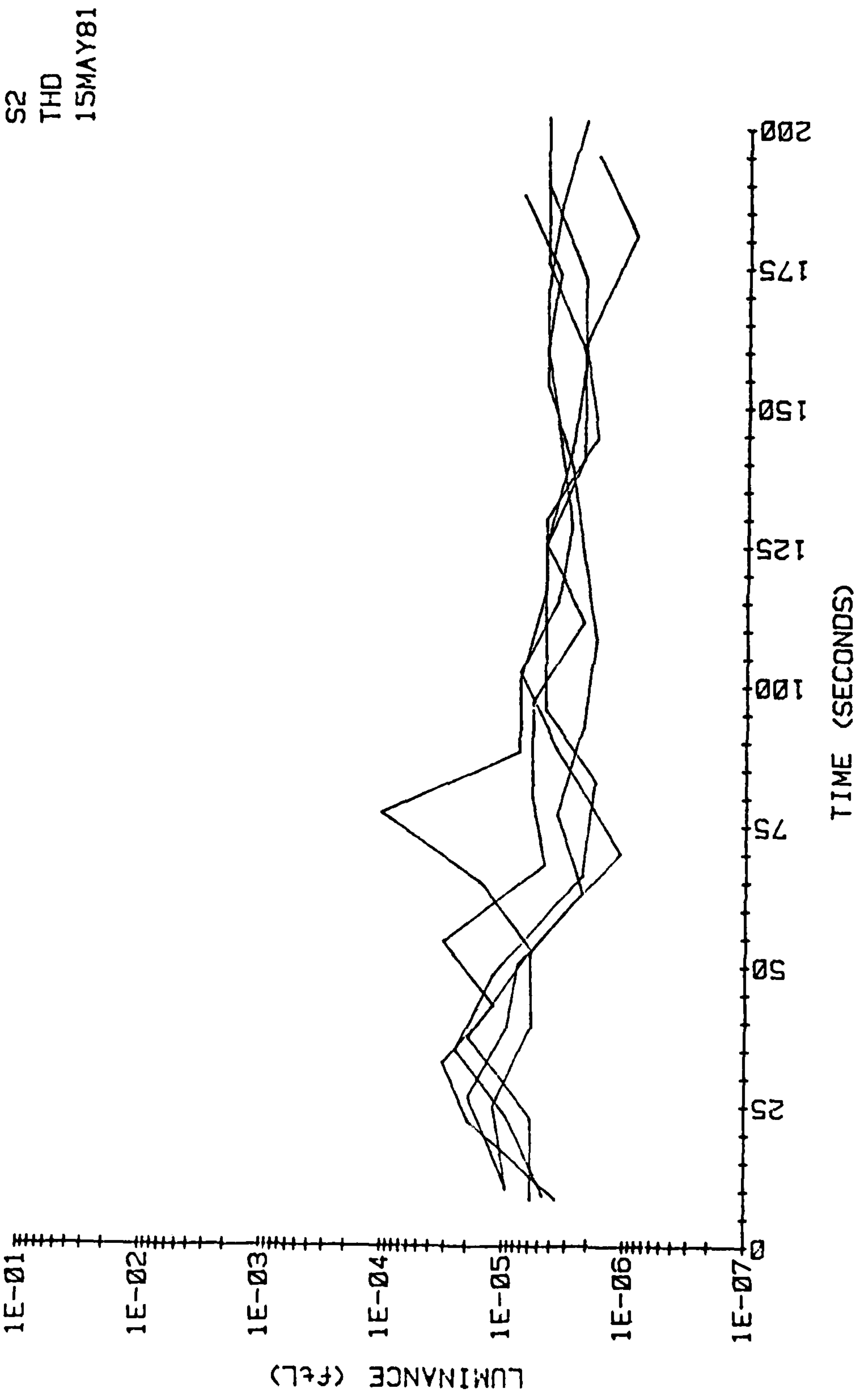
1E-Ø6
1E-Ø7
1E-Ø8
Ø
2
4
6
8
1Ø
12
14
SPATIAL FREQUENCY (CPD)
SQUARE WAVE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1E-03
1E-04
1E-05
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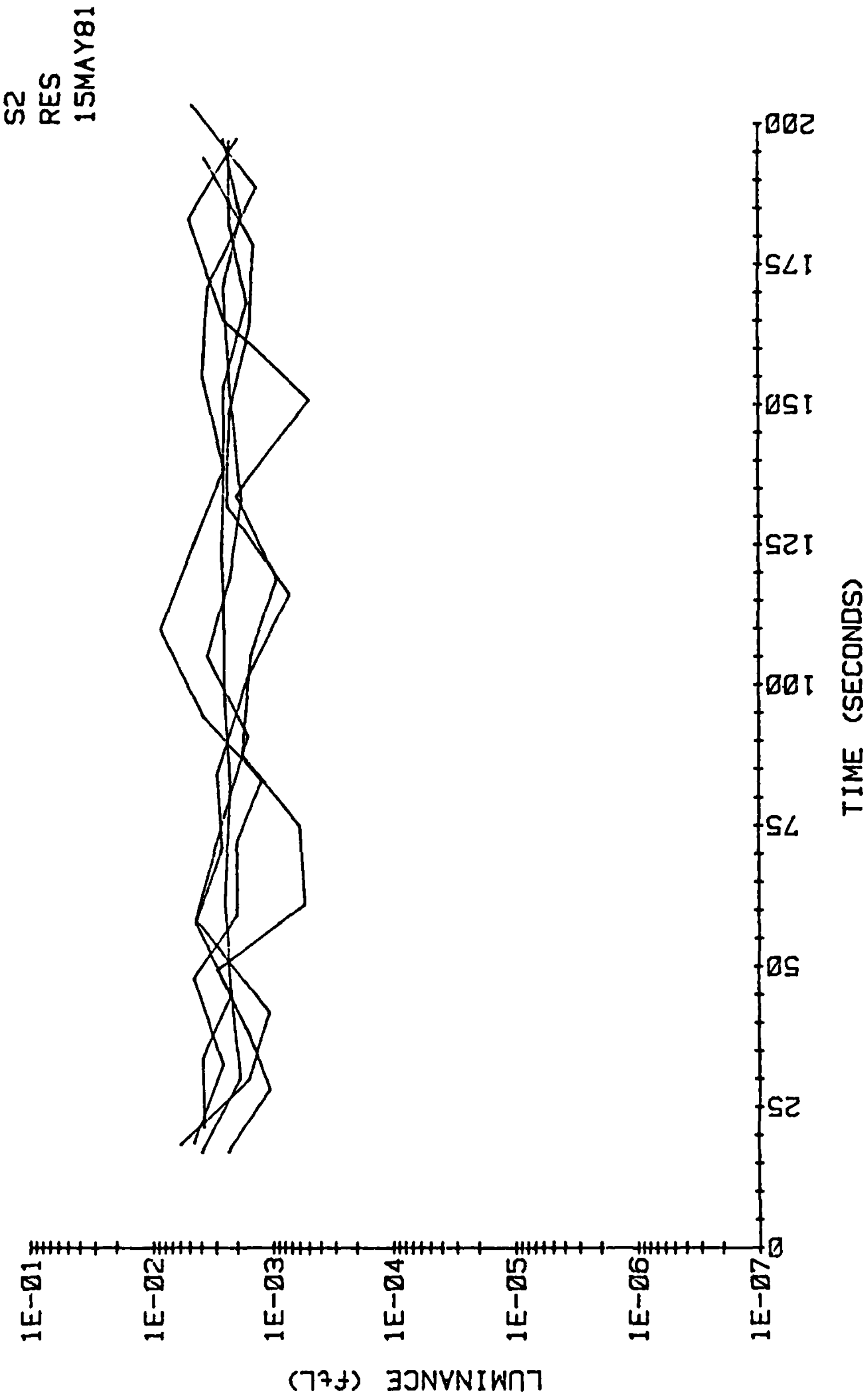
50
75
100
125
150
175
200
TIME (SECONDS)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1E-07
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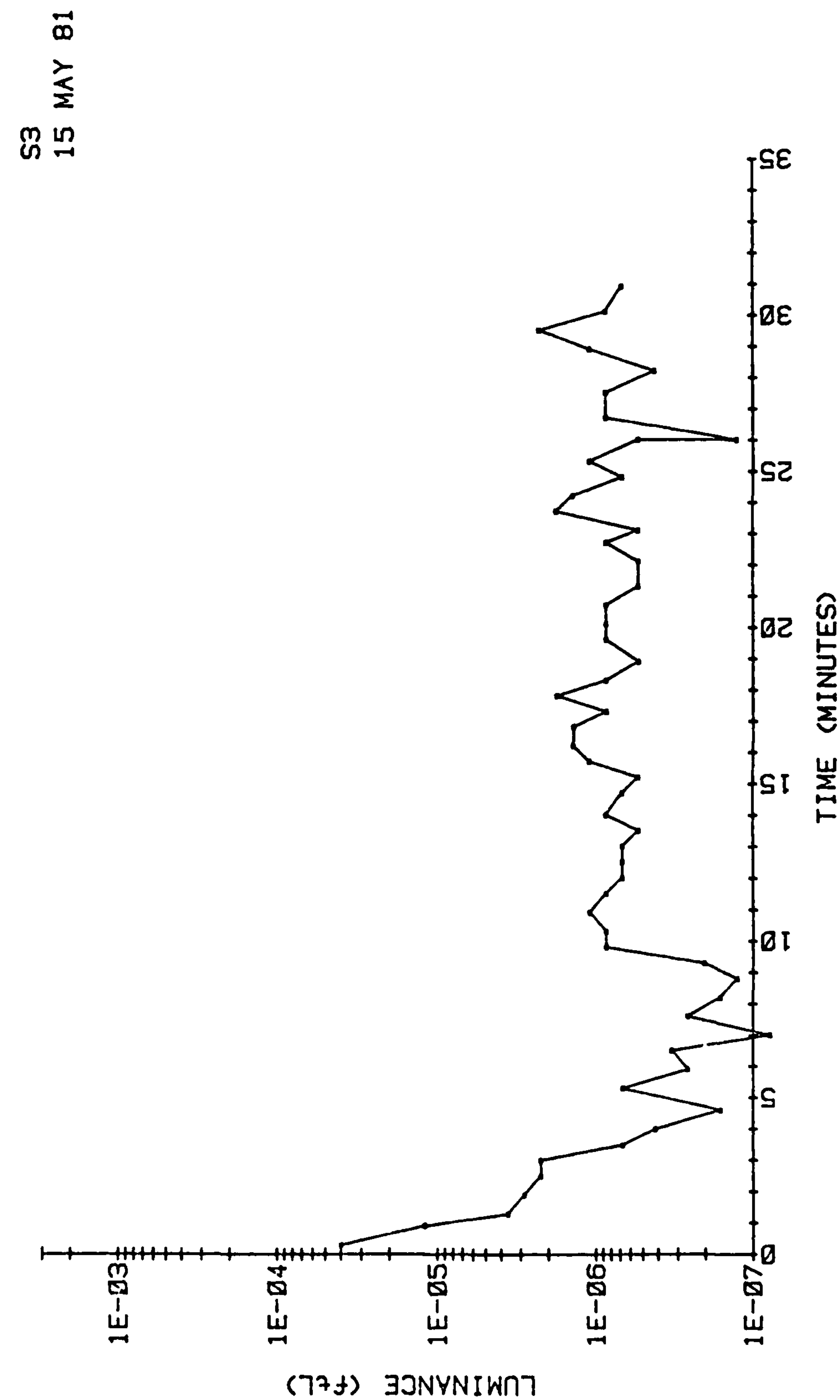
25
50
75
100
125
150
175
200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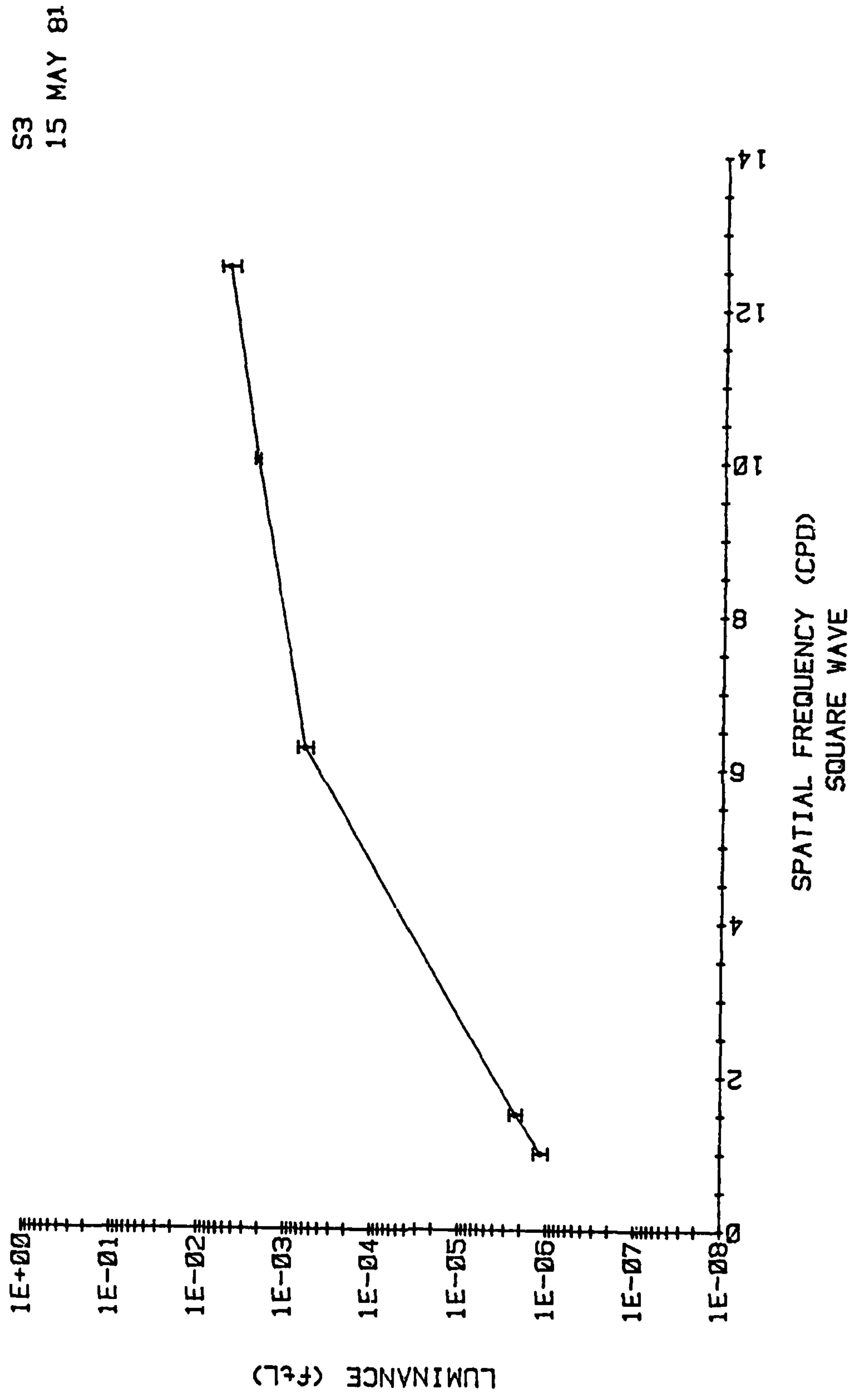
25
30
35
TIME (MINUTES)



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1E-04
1E-05
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4
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10
12
14
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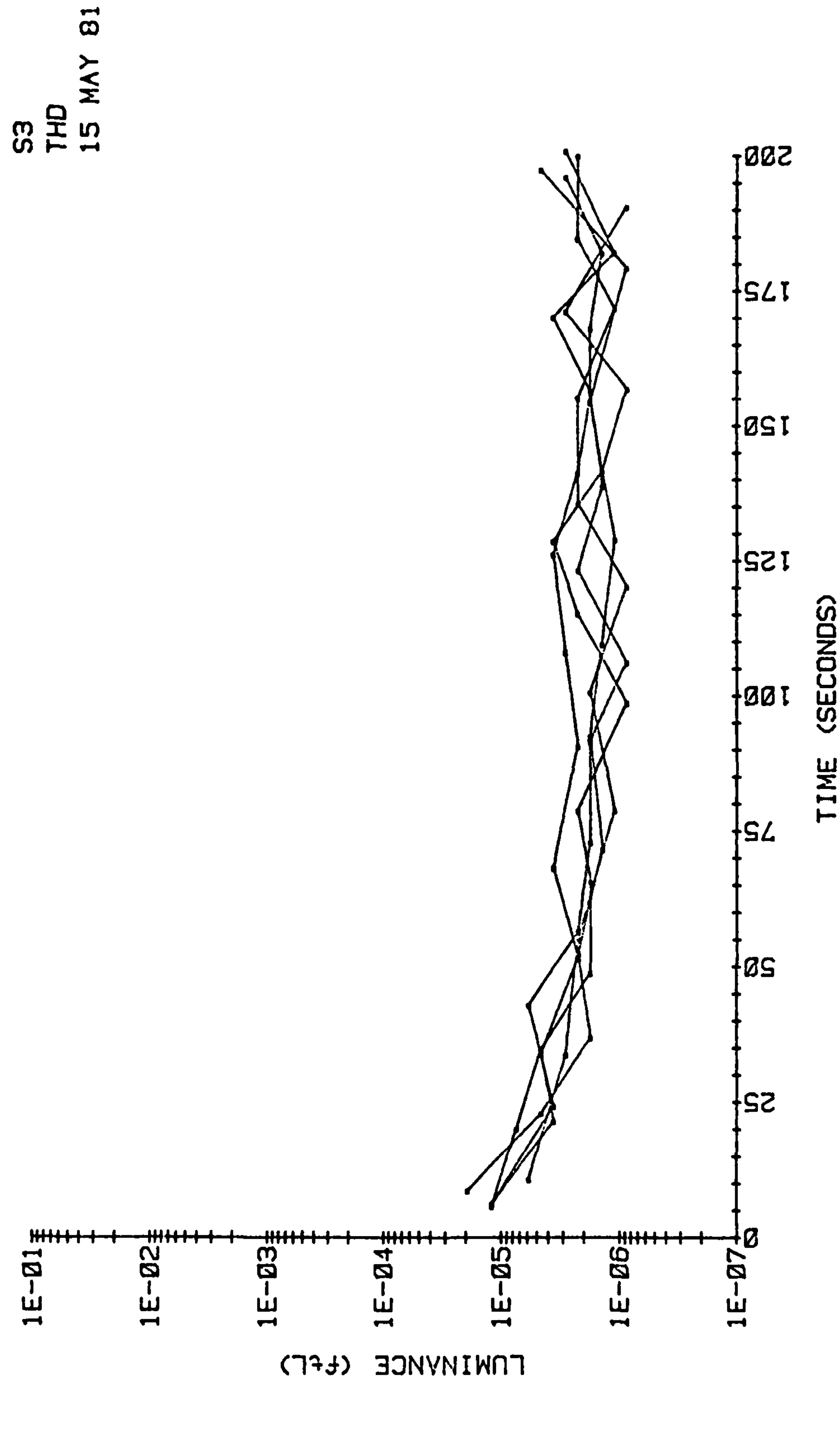
SQUARE WAVE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75
100
125
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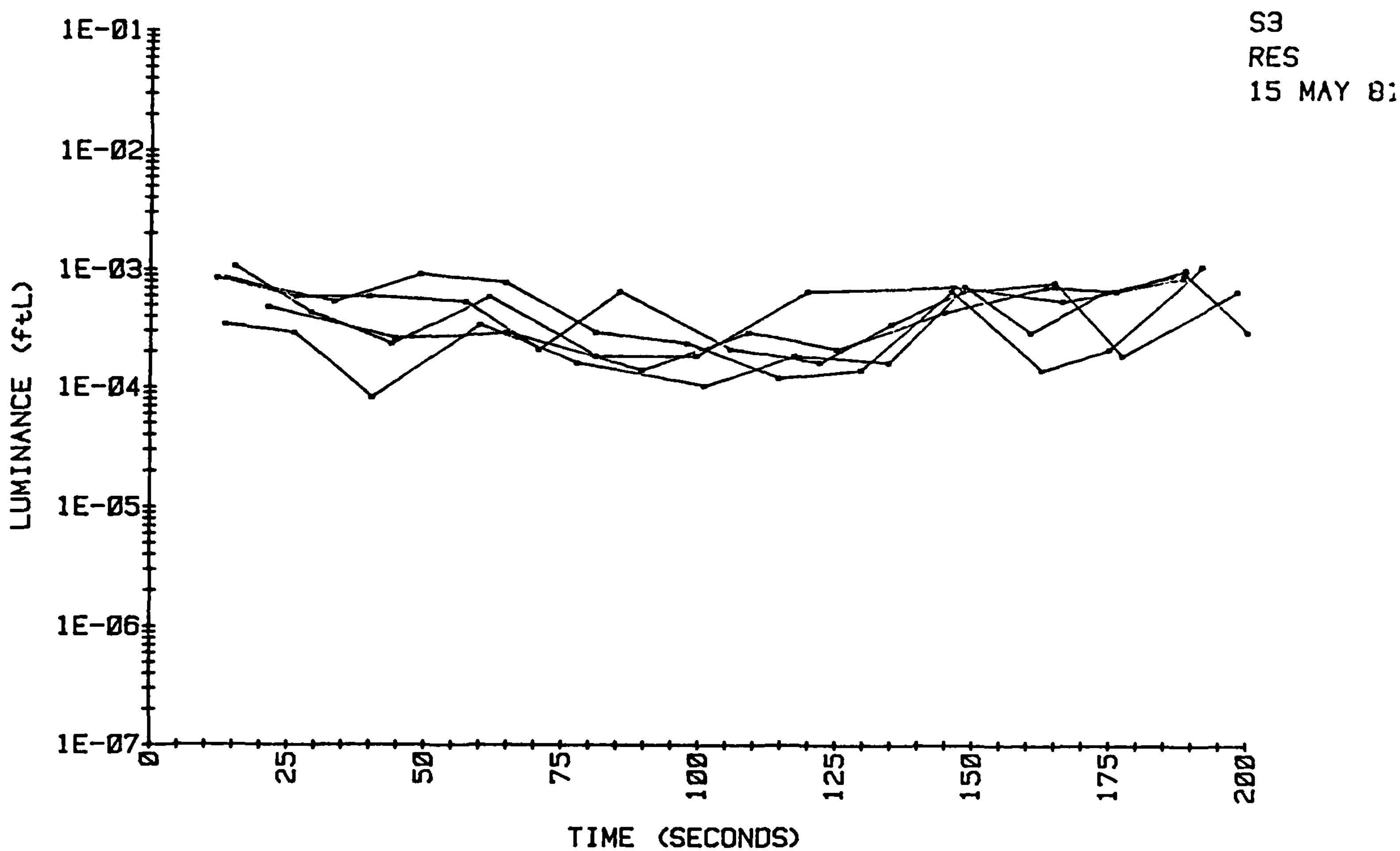
175
200
TIME (SECONDS)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100
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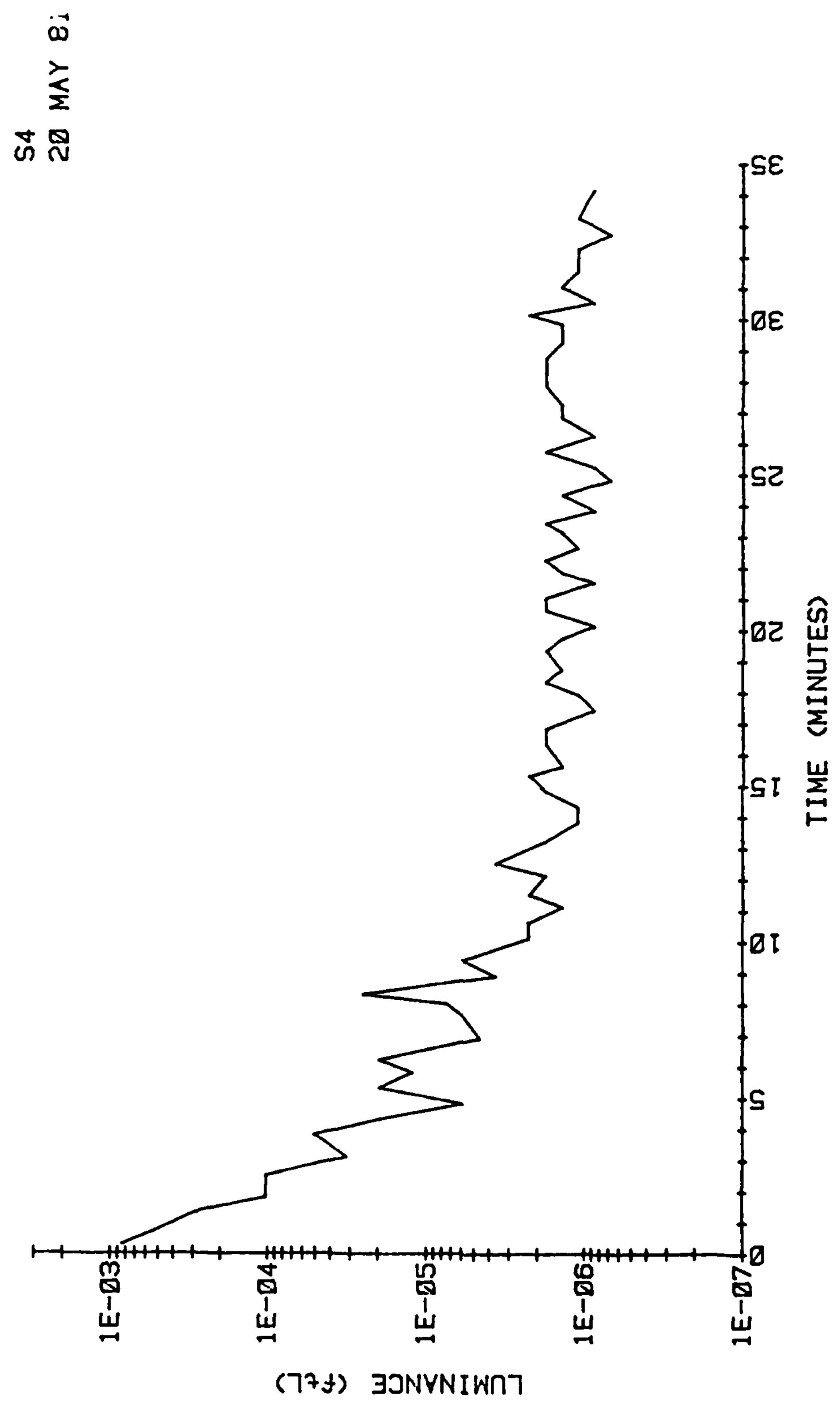
200
TIME (SECONDS)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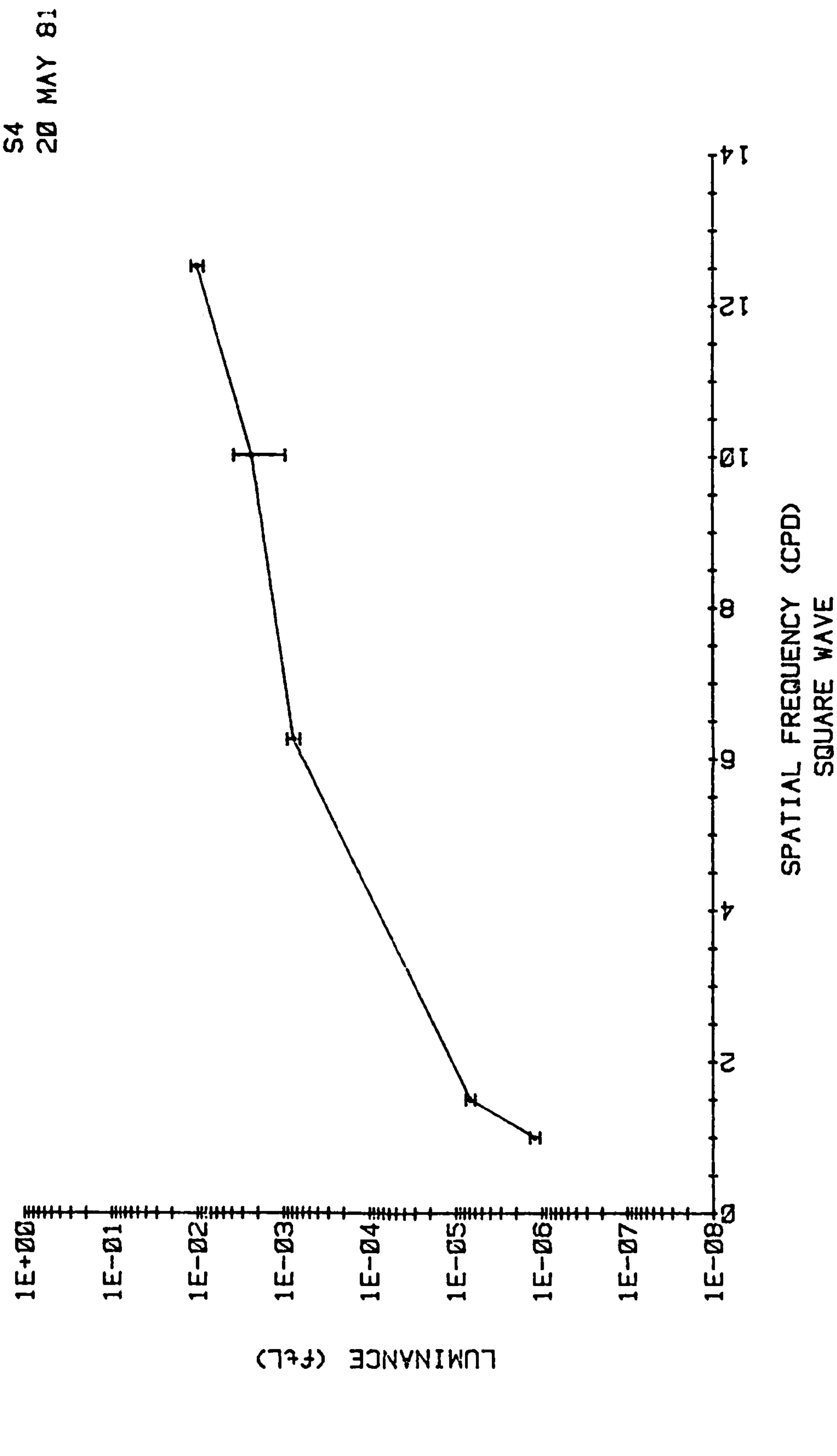
20
25
30
35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4
6
8
10
12
14
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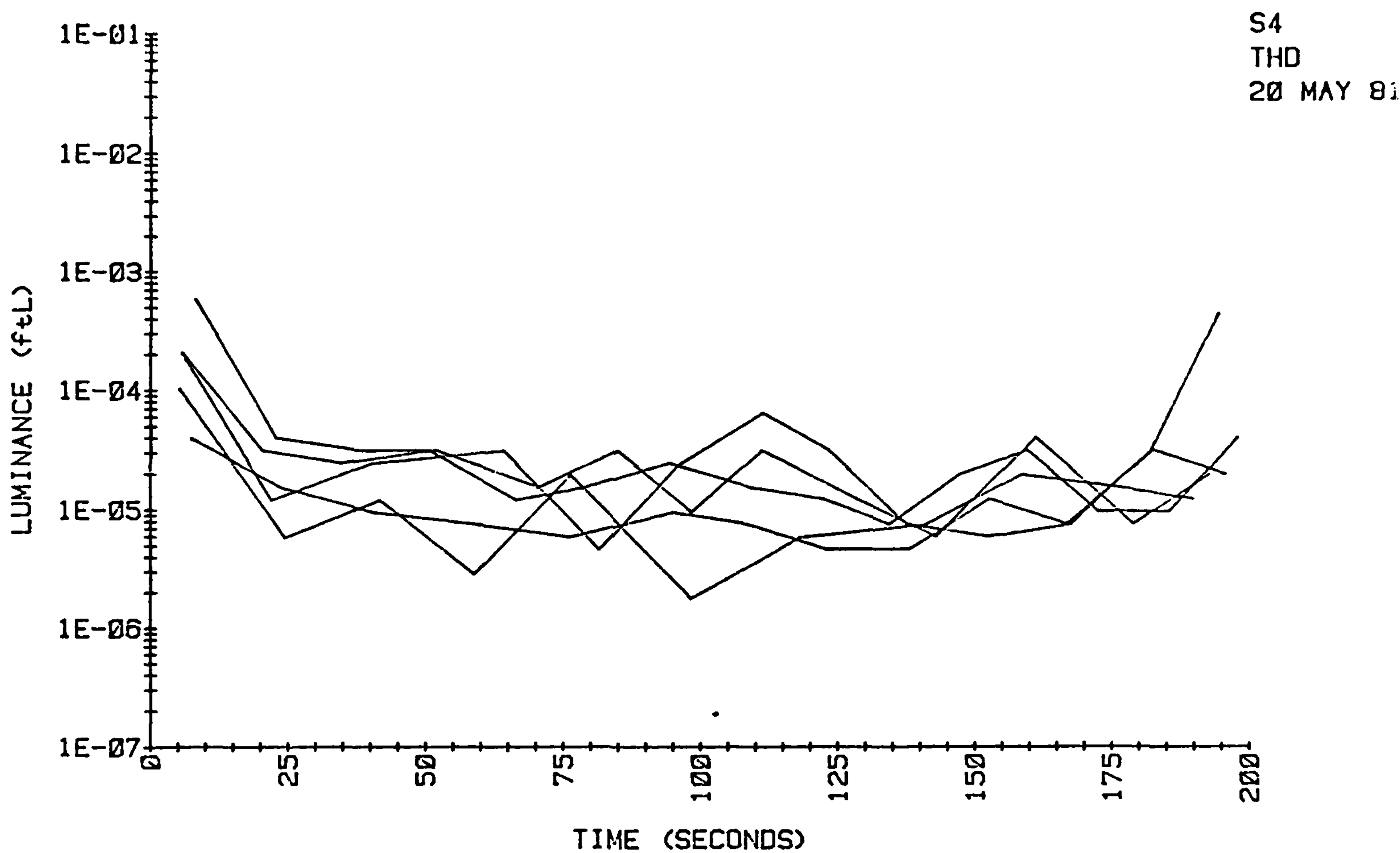
SQUARE WAVE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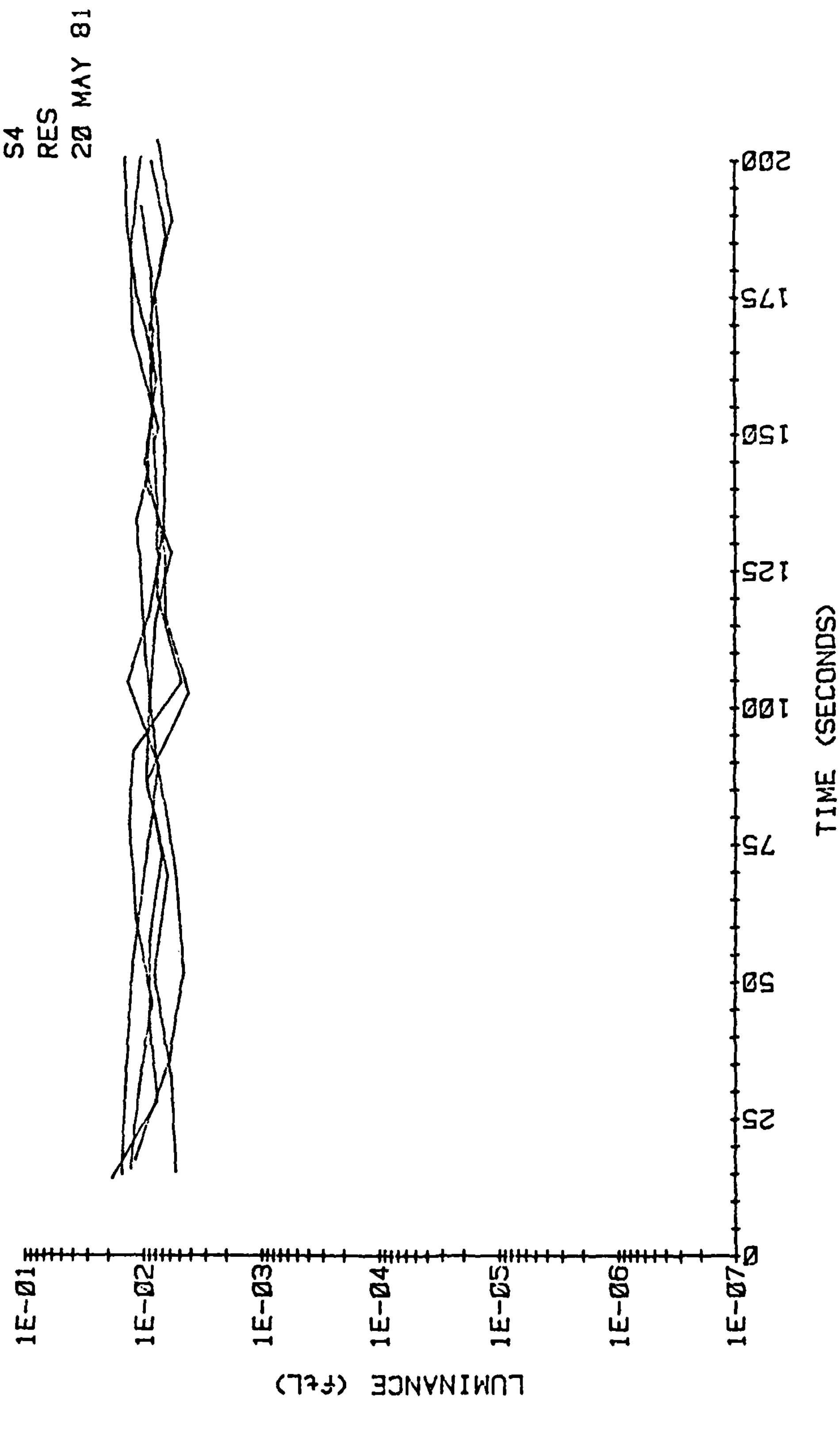
125
150
175
200
TIME (SECONDS)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125
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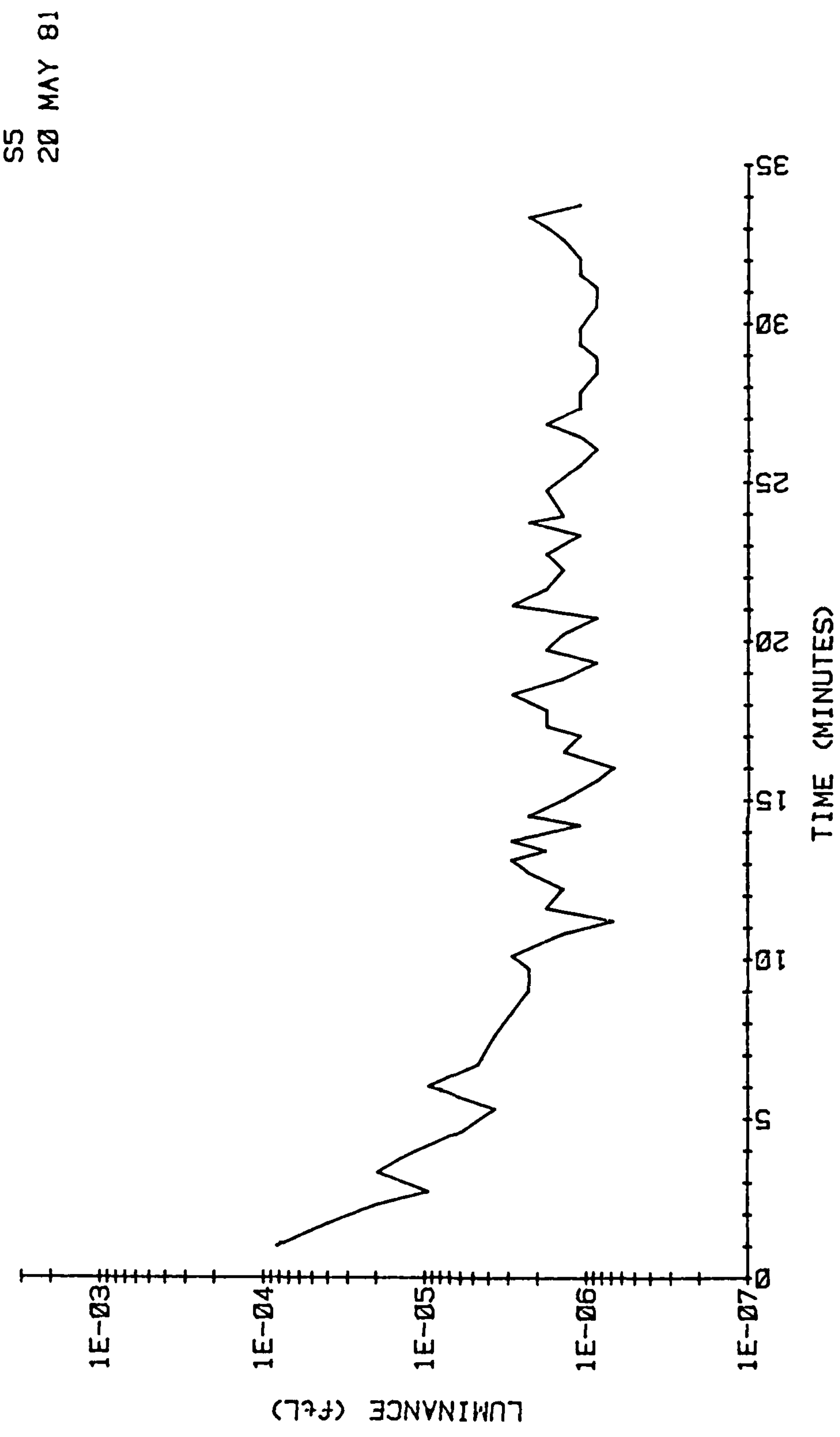
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2Ø MAY 81
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1E-Ø5
1E-Ø6
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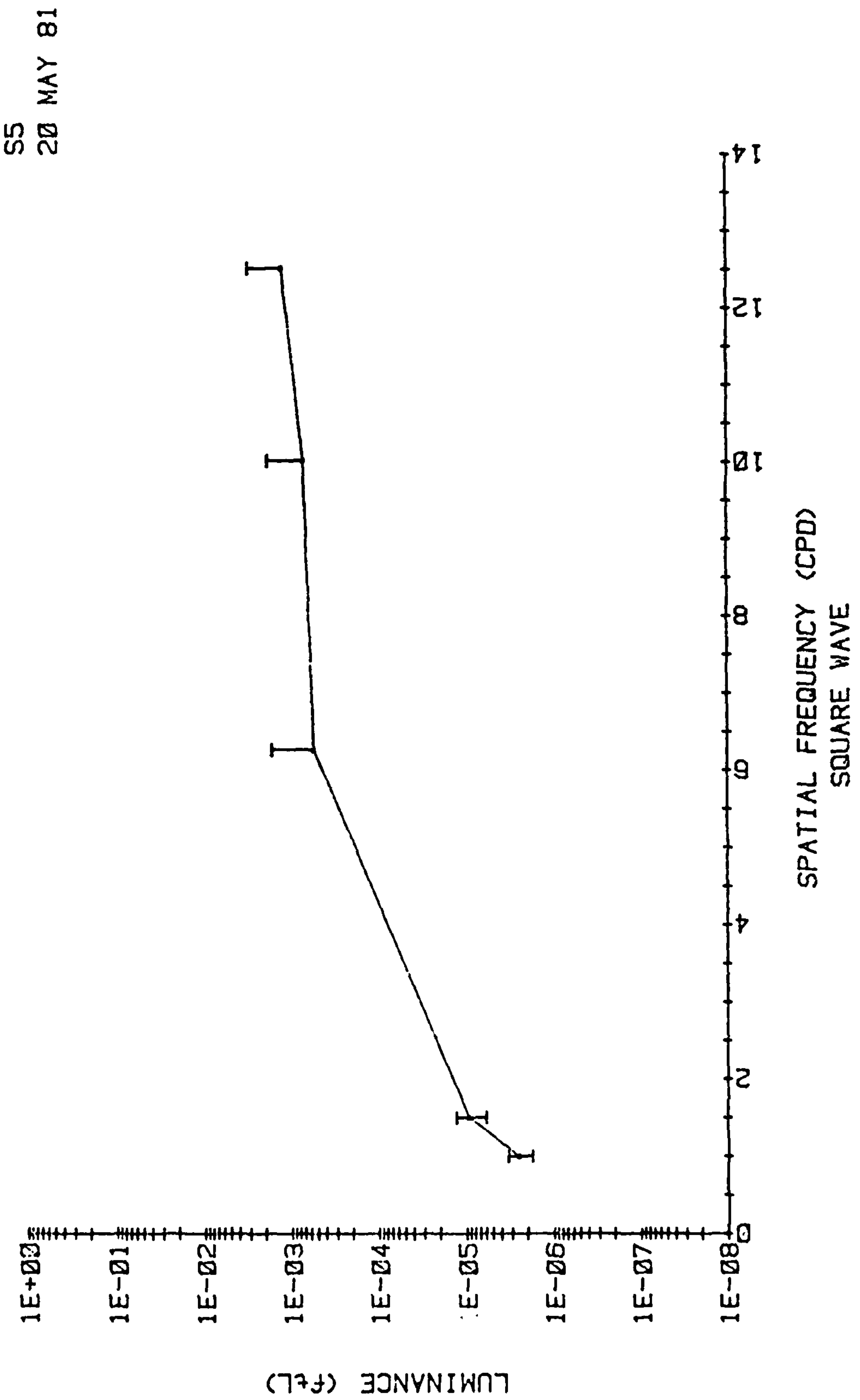
15
2Ø
25
3Ø
35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1E-03
1E-04
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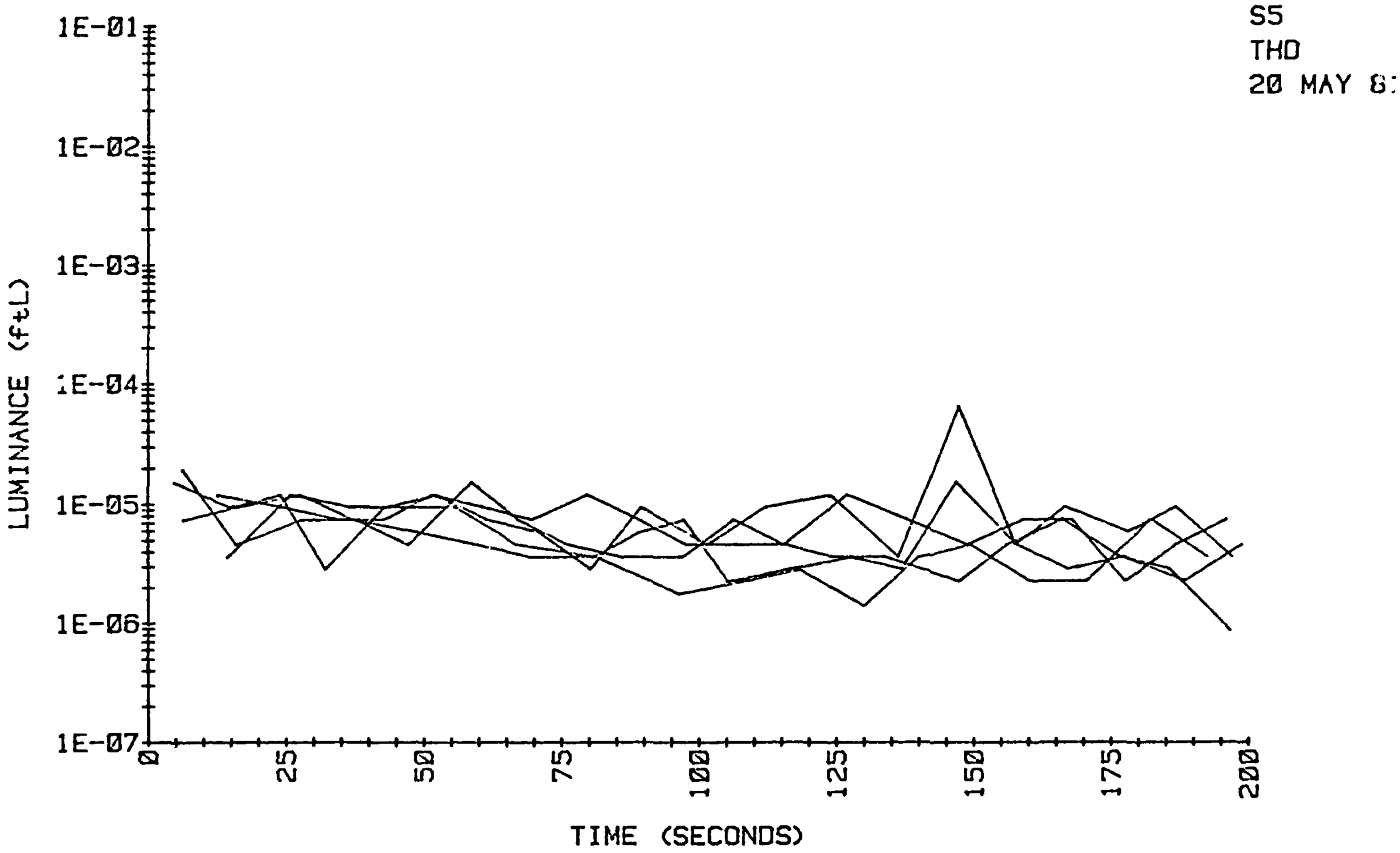
1E-08
0
2
4
6
8
10
12
14
SPATIAL FREQUENCY (CPD)
SQUARE WAVE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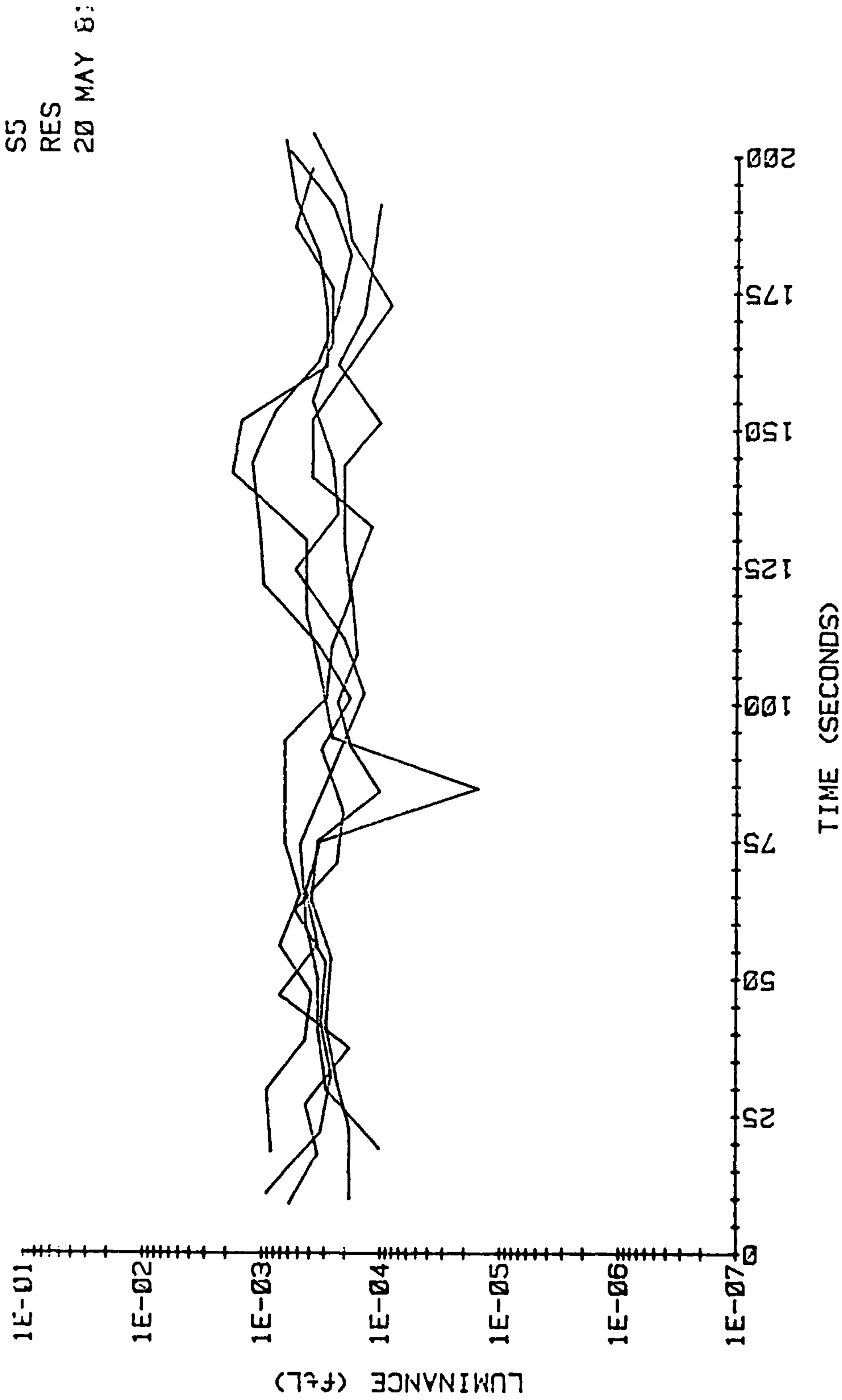
50
75
100
125
150
175
200
TIME (SECONDS)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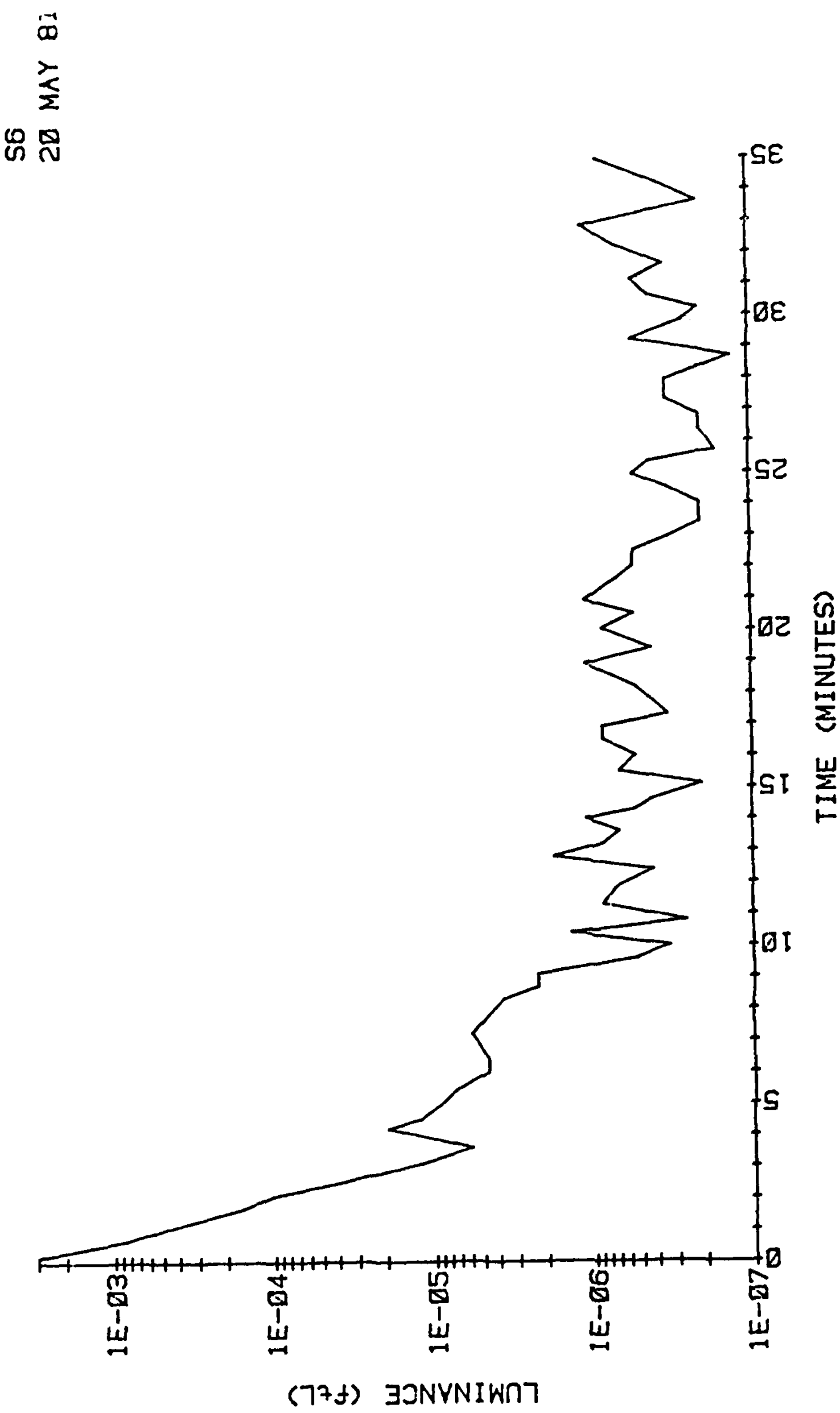
200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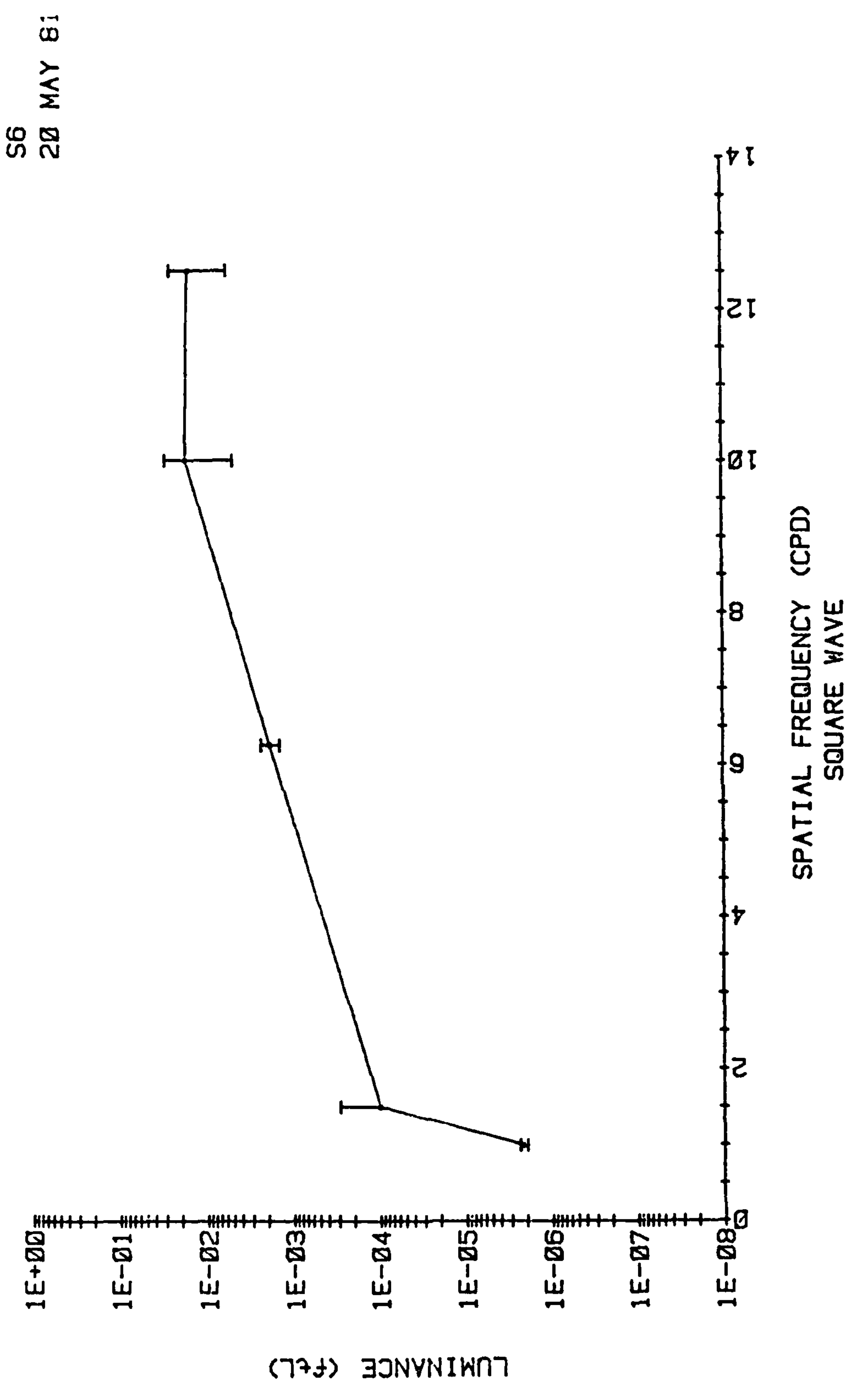
3Ø
35
TIME (MINUTES)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1E-03
1E-04
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4
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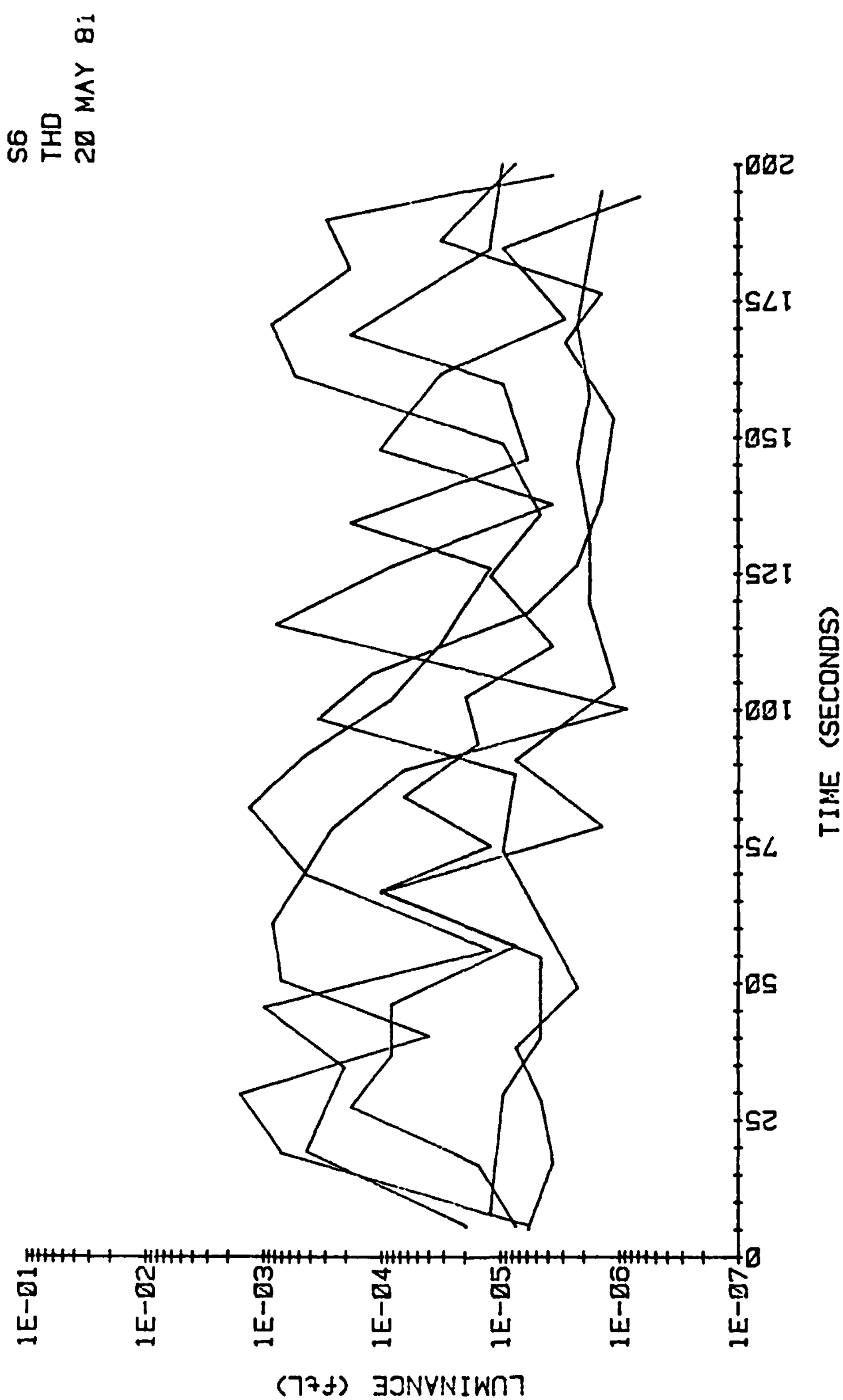
12
14
SPATIAL FREQUENCY (CPD)
SQUARE WAVE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20 MAY 81
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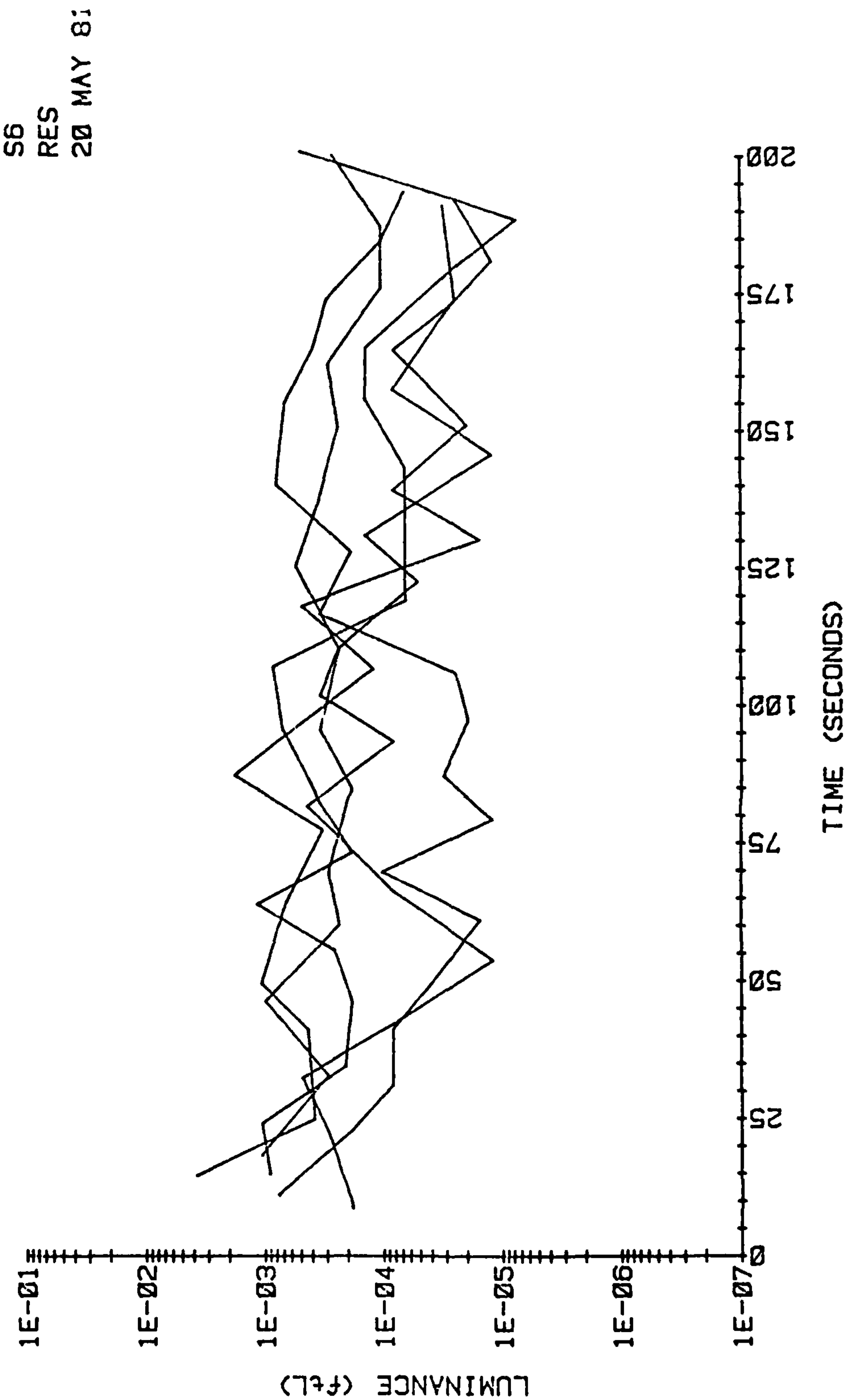
25
50
75
100
125
150
175
200
TIME (SECONDS)


S6
RES
20 MAY 81
LUMINANCE (ftL)
1E-01
1E-02
1E-03
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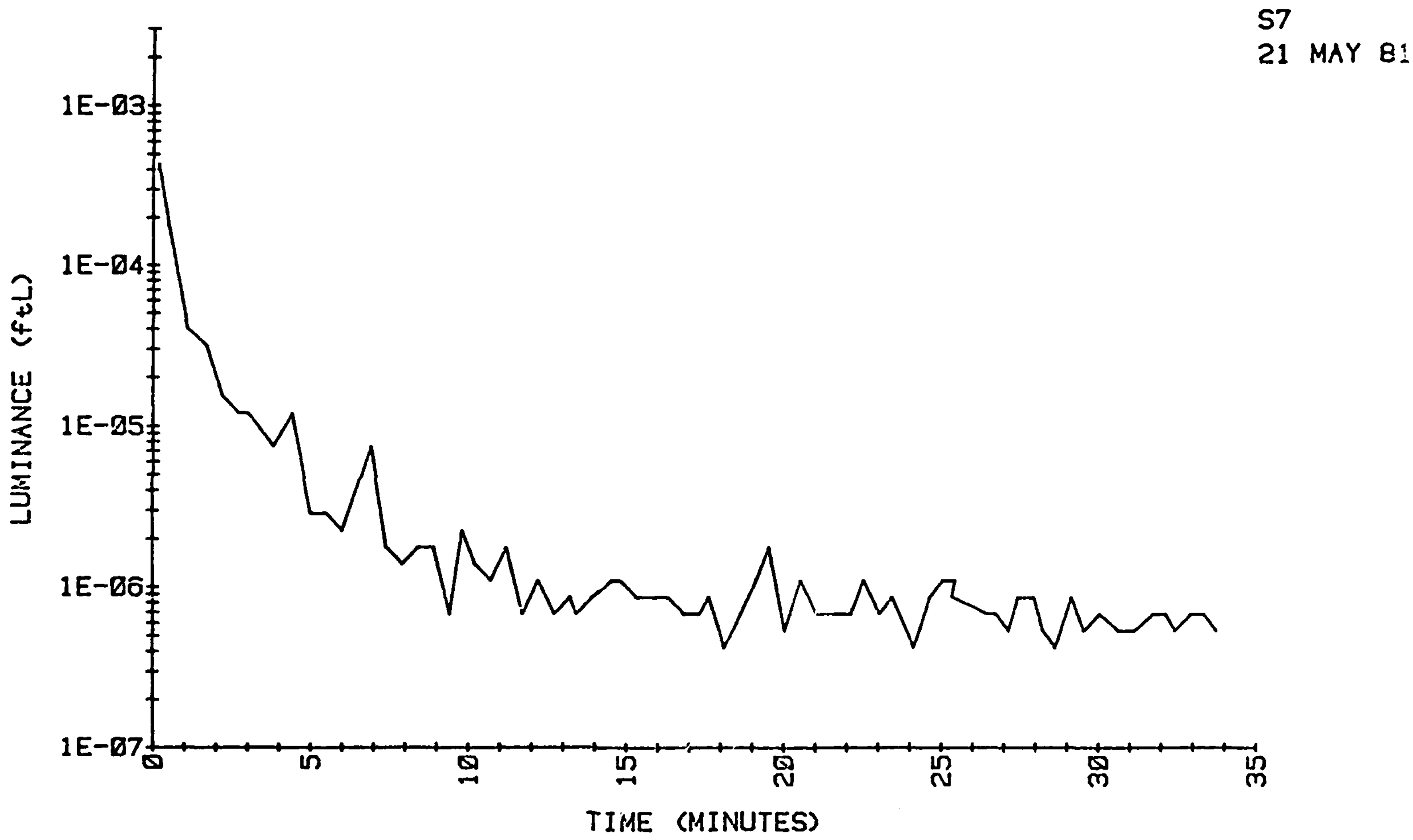
1E-05
1E-06
1E-07
TIME (SECONDS)
0
25
50
75
100
125
150
175
200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15
20
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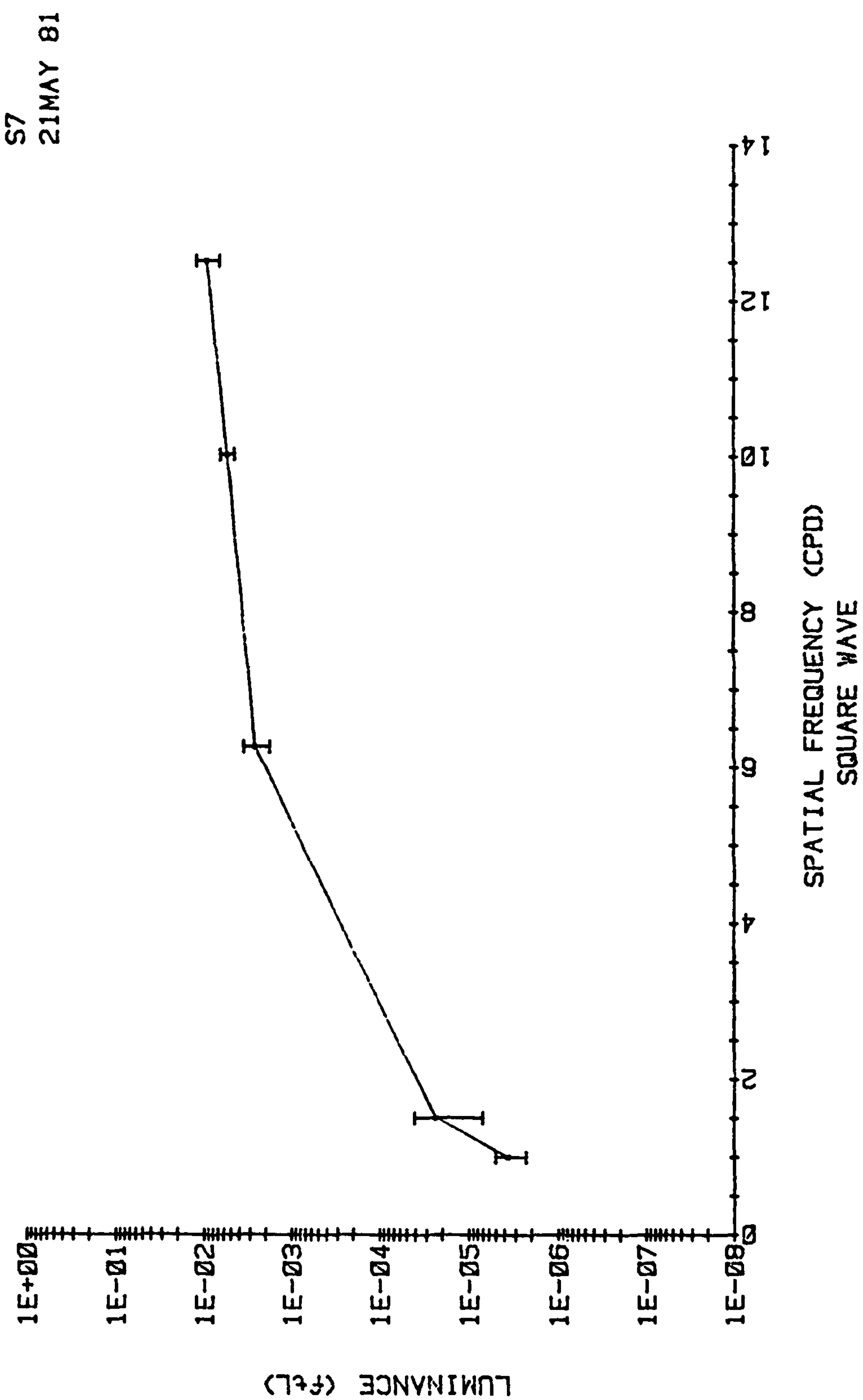
35
TIME (MINUTES)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1E-08
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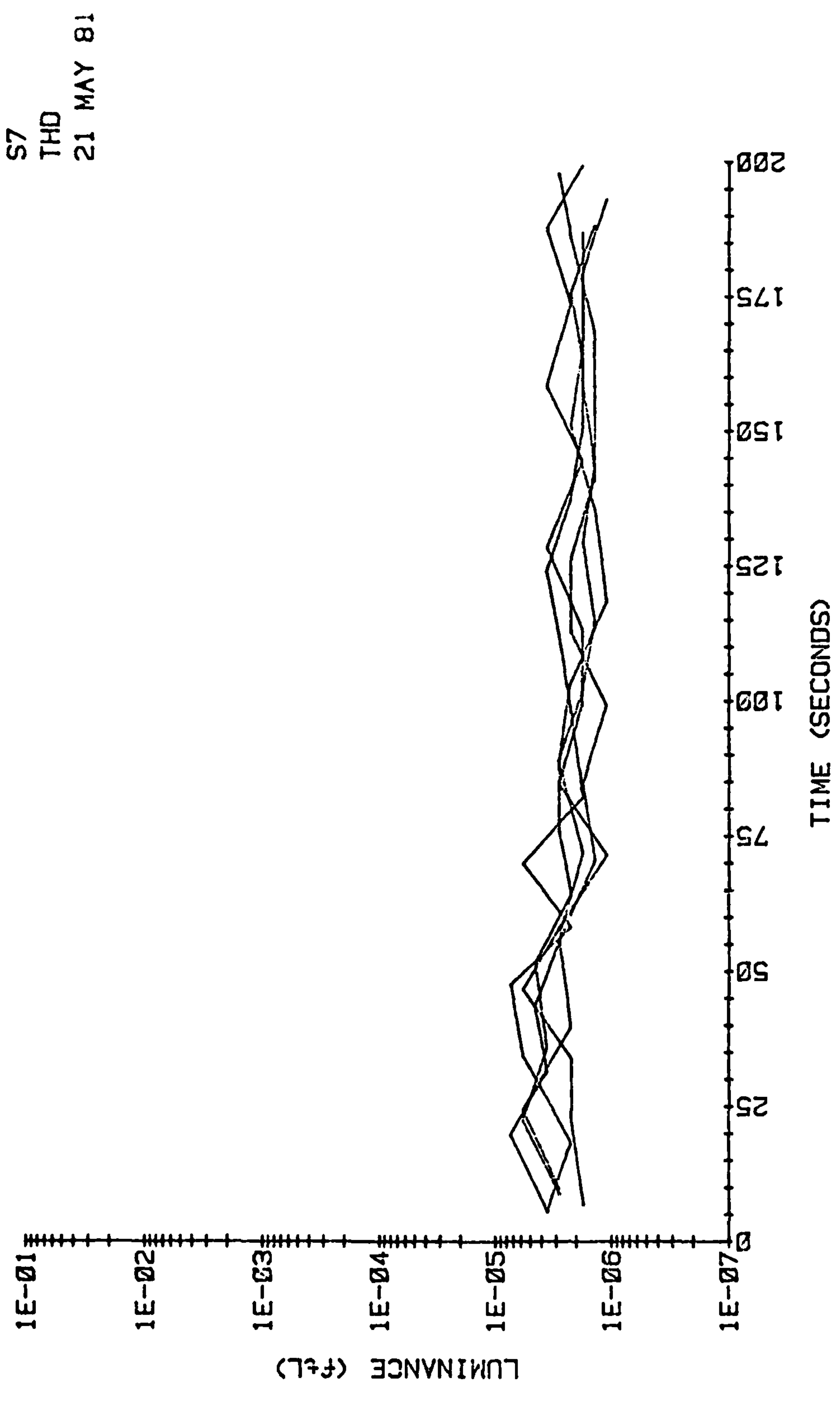
10
12
14
SPATIAL FREQUENCY (CPD)
SQUARE WAVE



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LUMINANCE (ftL)
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TIME (SECONDS)
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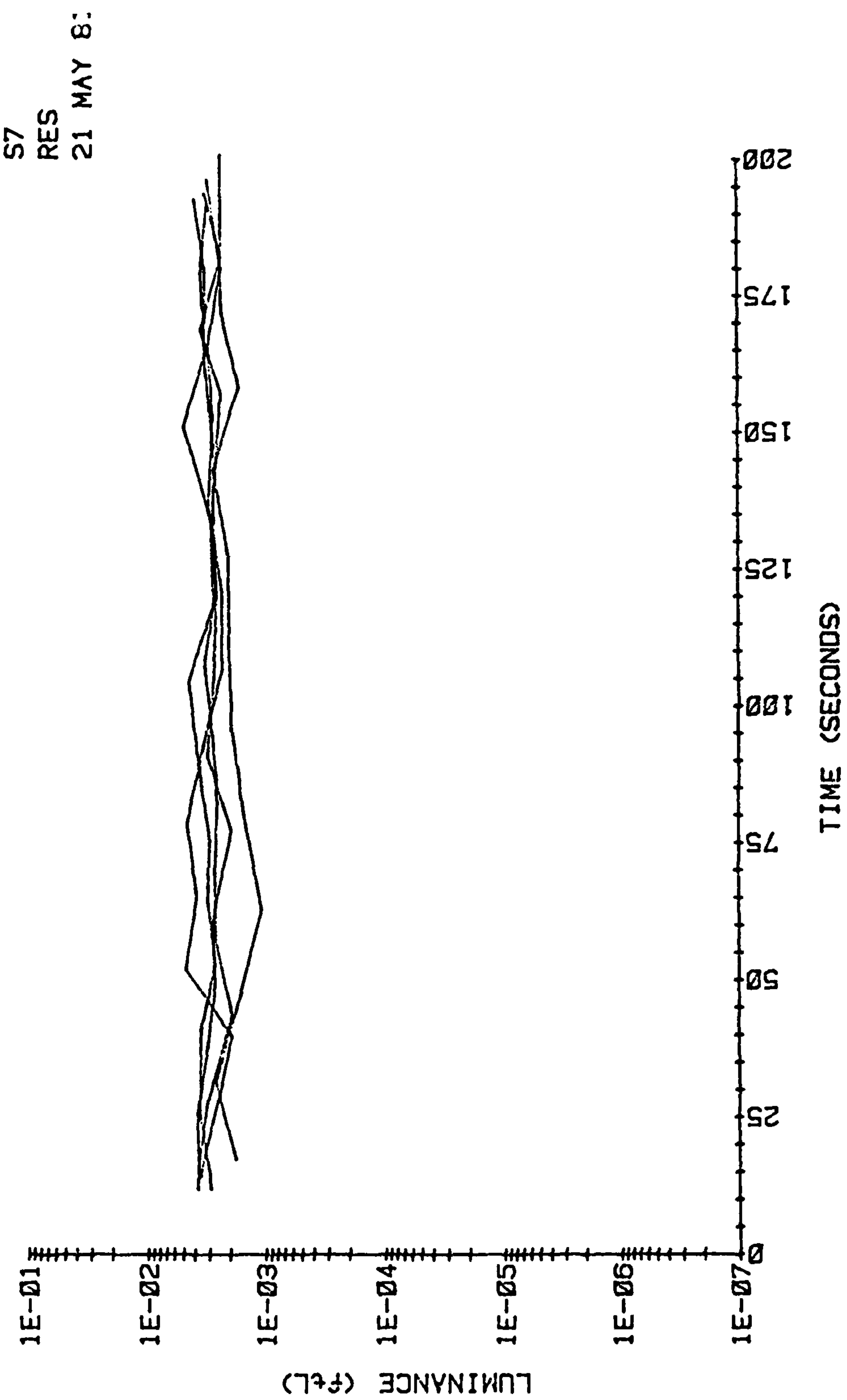
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TIME (SECONDS)
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125
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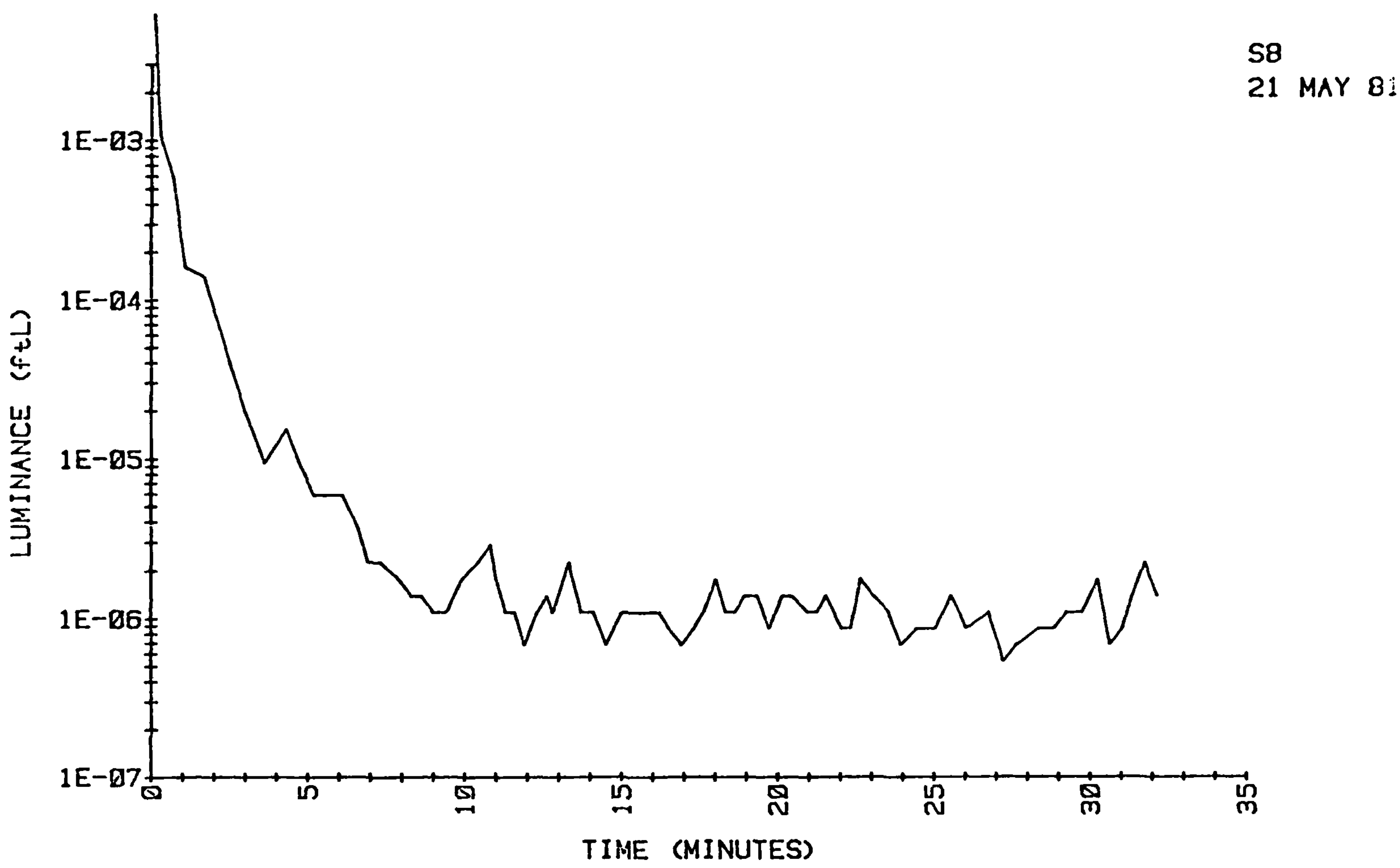
175
200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25
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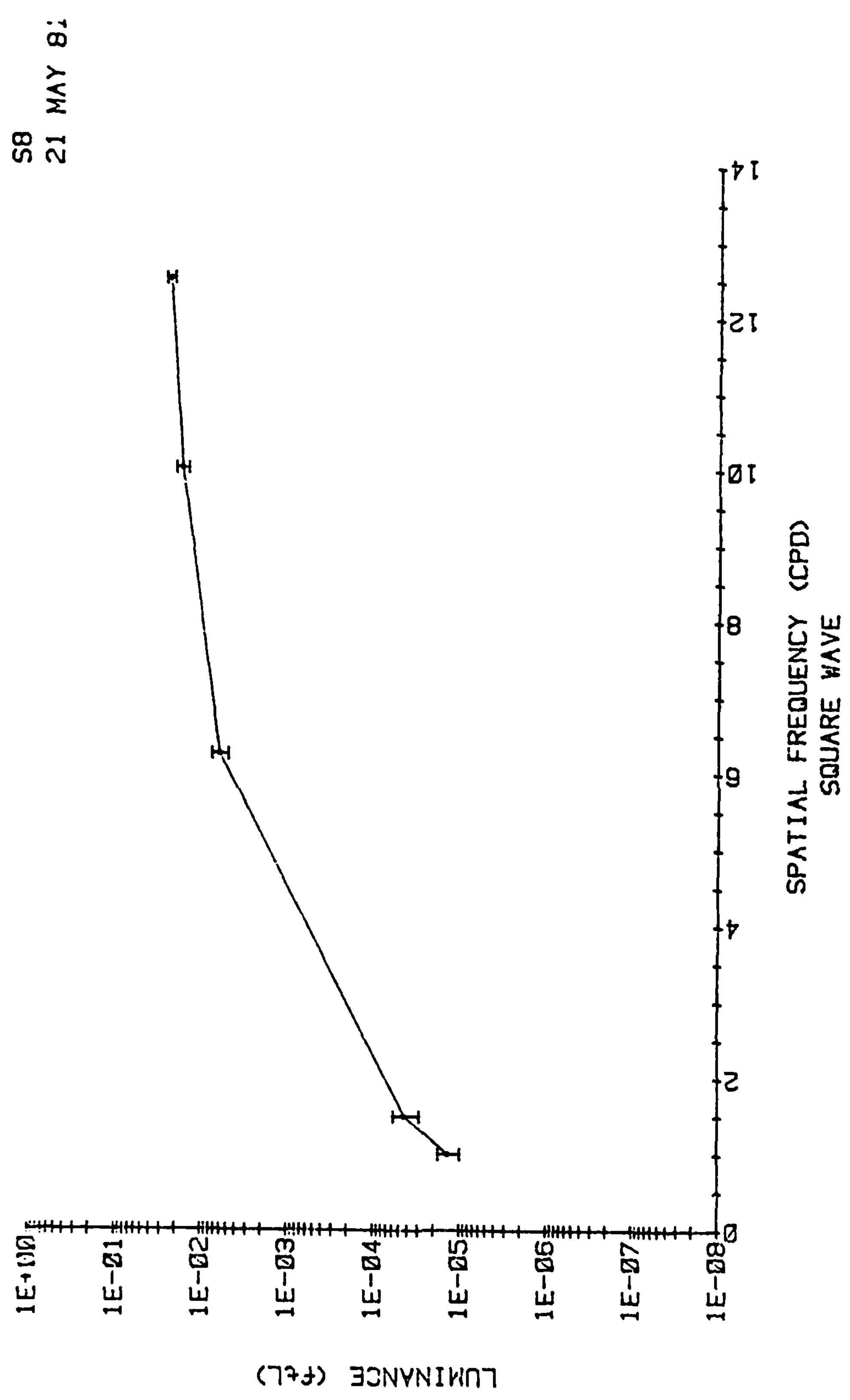
35
TIME (MINUTES)



S8
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SPATIAL FREQUENCY (CPD)
SQUARE WAVE
LUMINANCE (ftL)
1E+00
1E-01
1E-02
1E-03
1E-04
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1E-06
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1E-08
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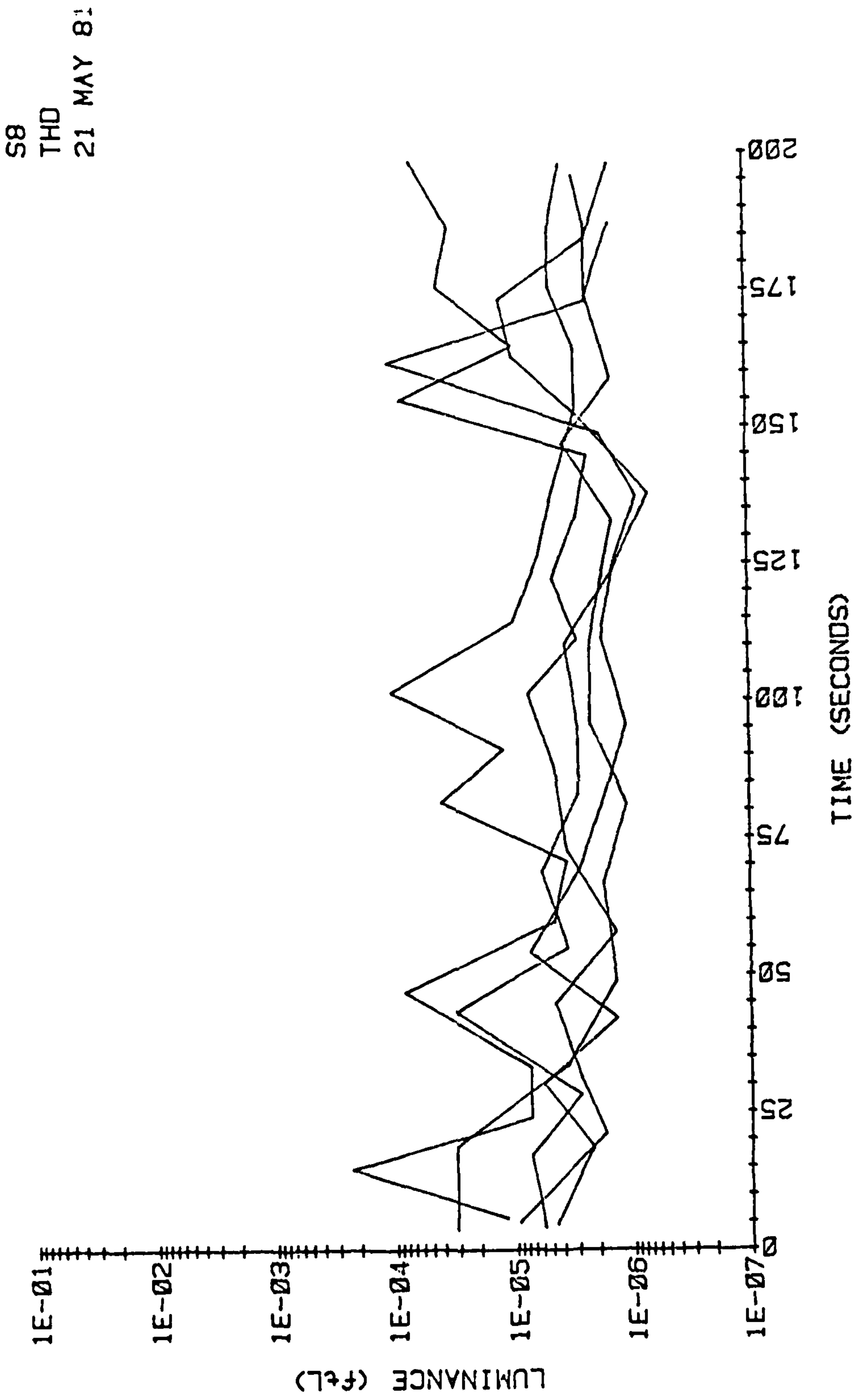
12
14



S8
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LUMINANCE (ftL)
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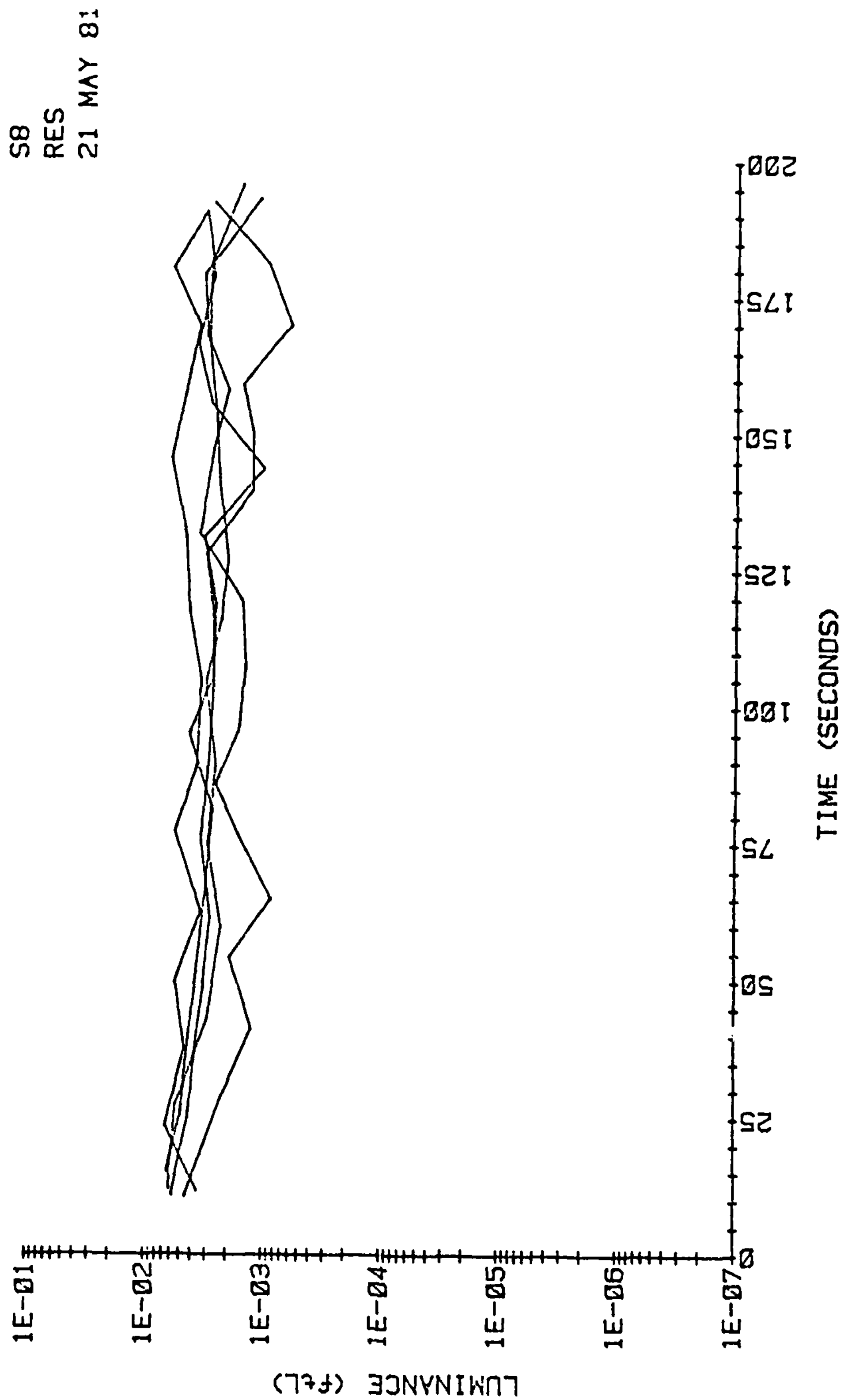
TIME (SECONDS)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LUMINANCE (fL)
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TIME (SECONDS)
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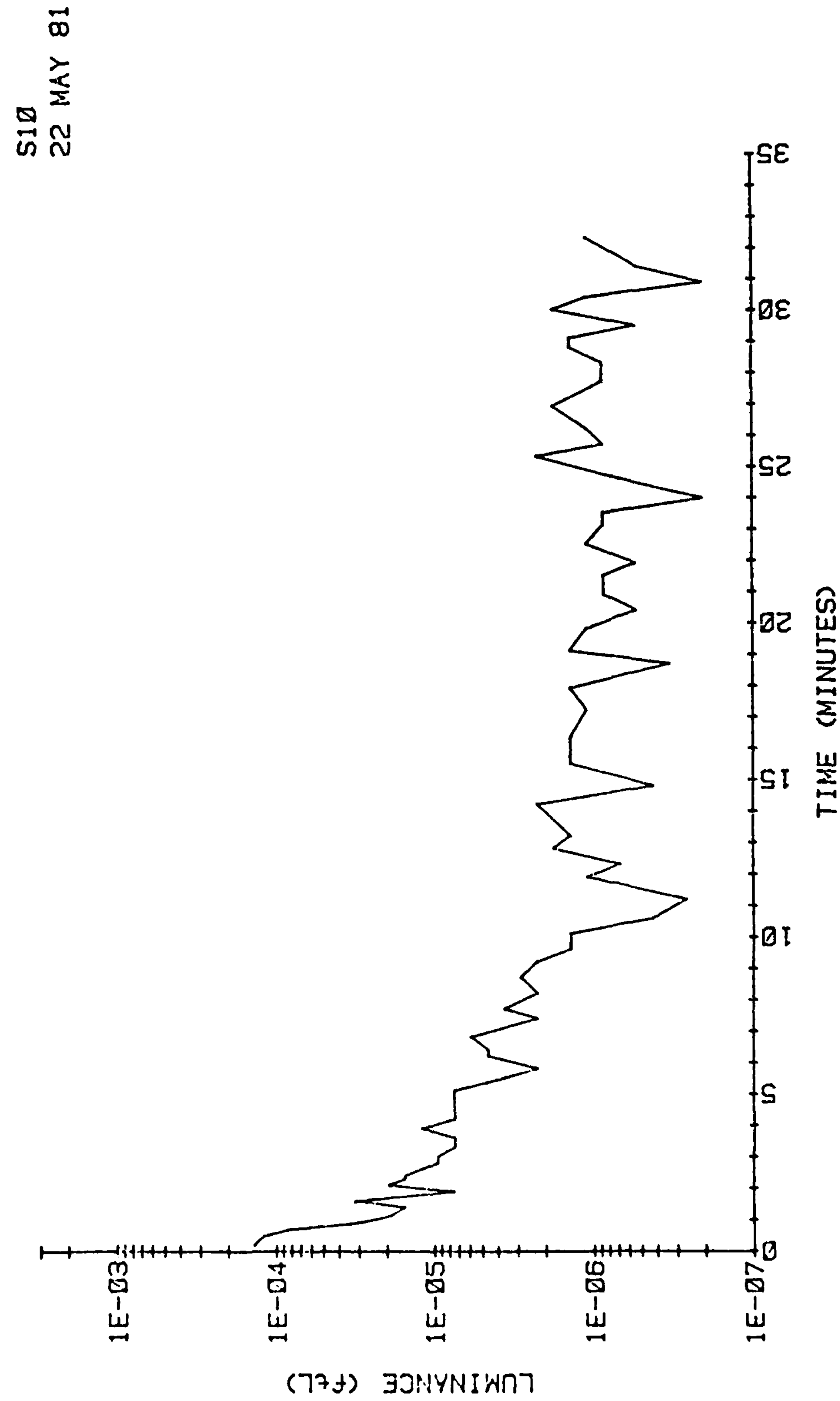

S1Ø
22 MAY 81
LUMINANCE (fL)
1E-03
1E-Ø4
1E-Ø5
1E-Ø6
1E-Ø7
TIME (MINUTES)
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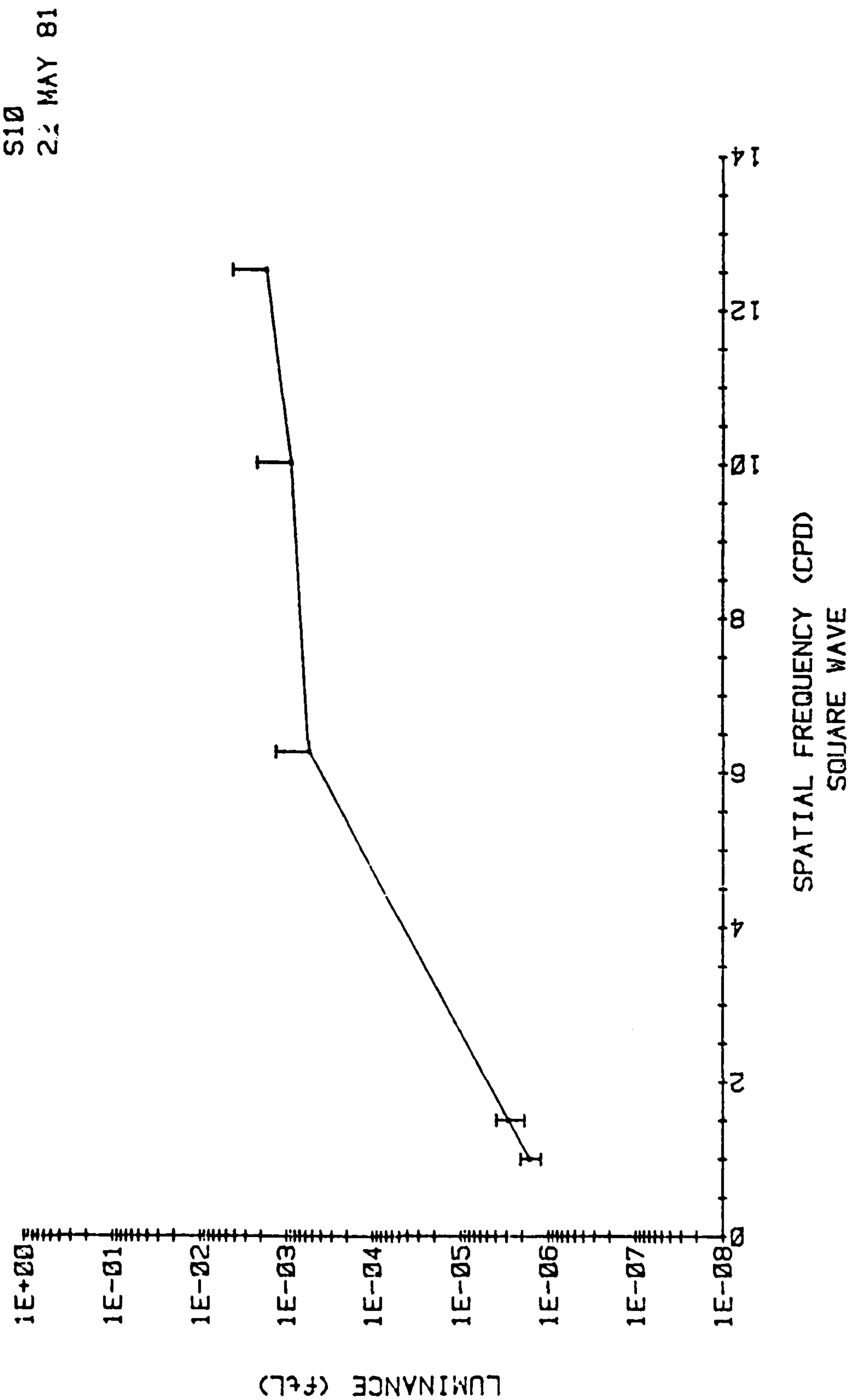

S1Ø
MAY 81
LUMINANCE (f+L)
1E+ØØ
1E-Ø1
1E-Ø2
1E-Ø3
1E-Ø4
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1E-Ø6
1E-Ø7
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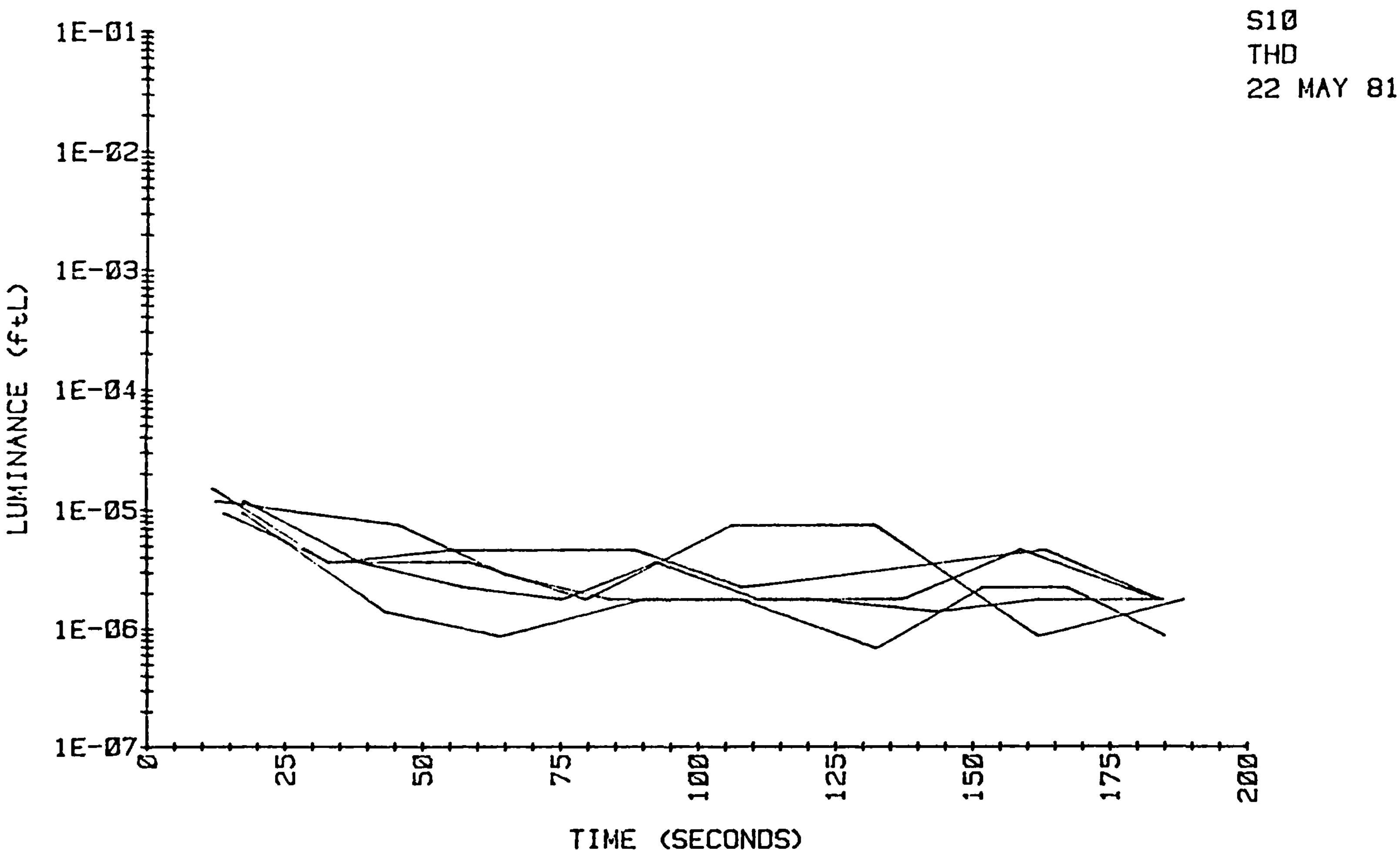
14
SPATIAL FREQUENCY (CPD)
SQUARE WAVE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THD
22 MAY 81
1E-01
1E-02
1E-03
1E-04
1E-05
1E-06
1E-07
LUMINANCE (ftL)
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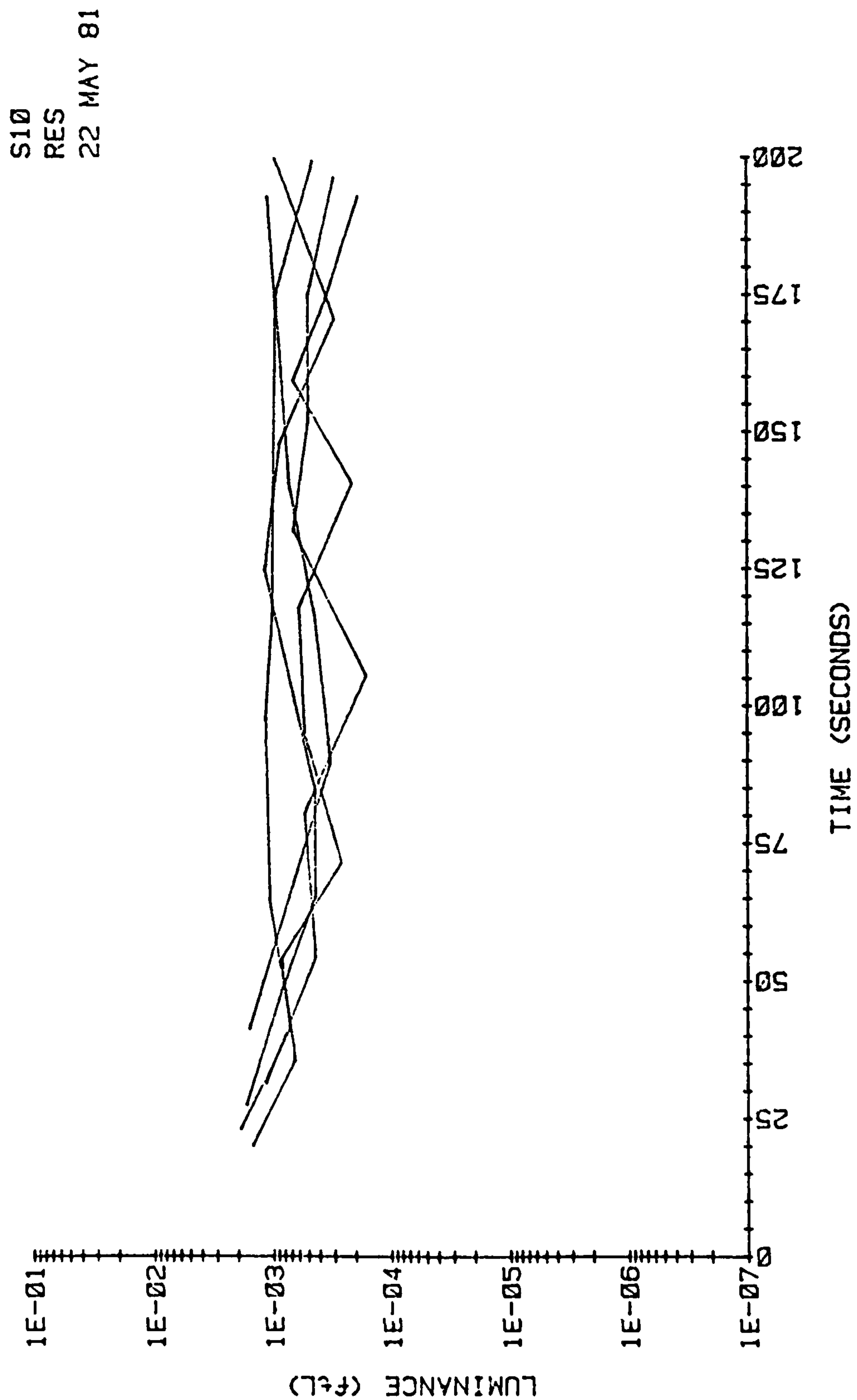
TIME (SECONDS)


S1Ø
RES
22 MAY 81
LUMINANCE (FtL)
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TIME (SECONDS)
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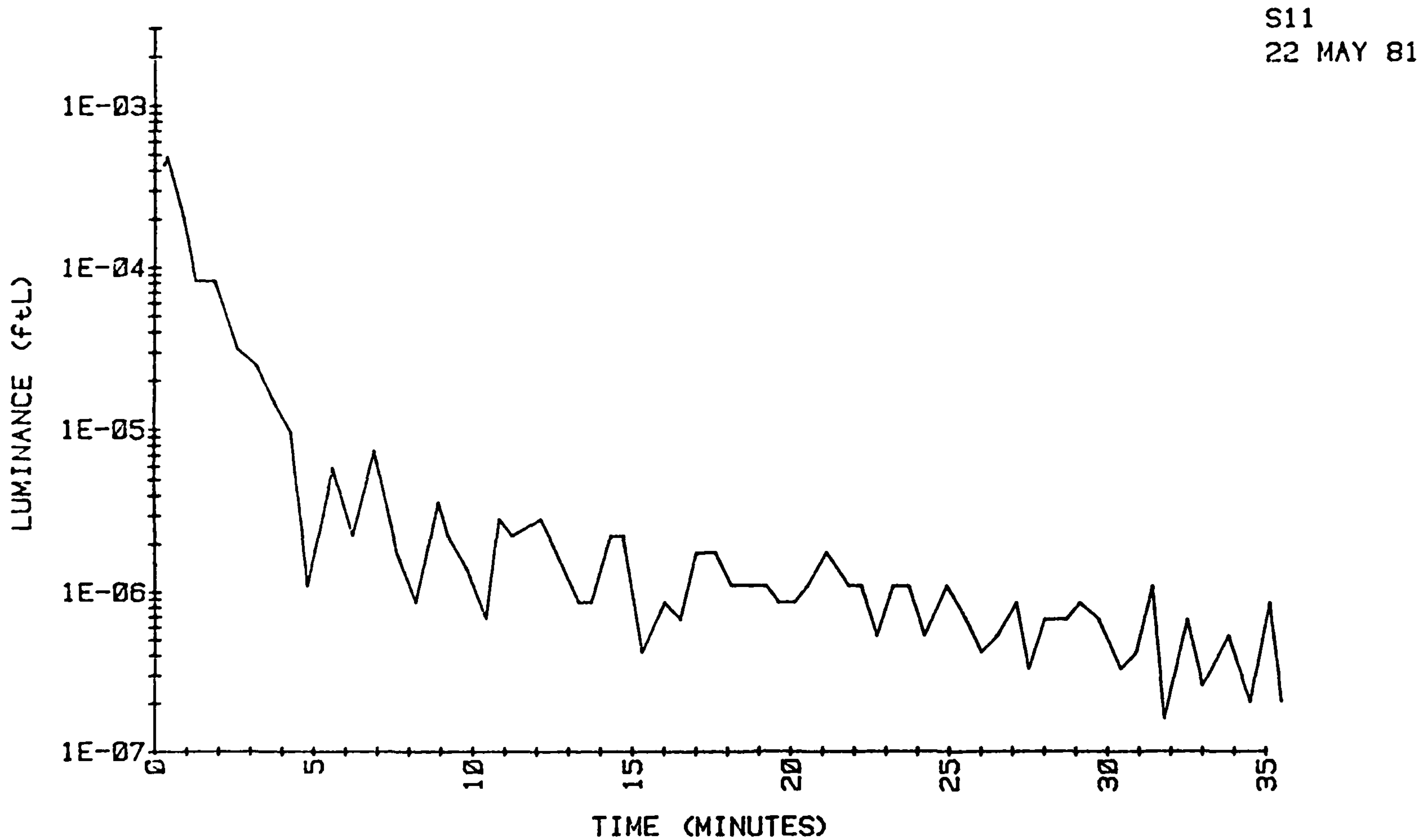
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LUMINANCE (ftL)
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1E-05
1E-06
1E-07
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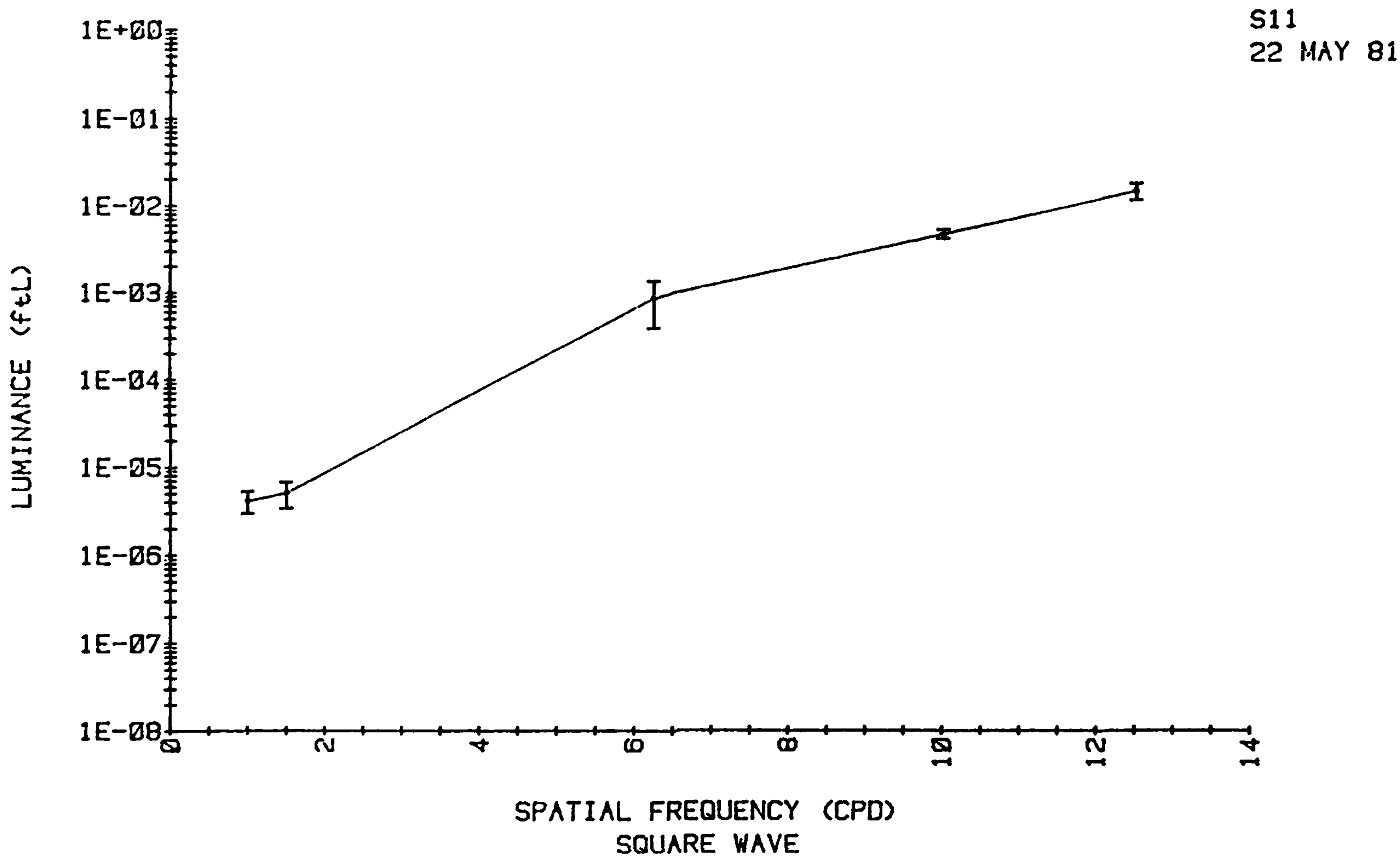
TIME (MINUTES)


S11
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LUMINANCE (ftL)
1E+00
1E-01
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1E-04
1E-05
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1E-07
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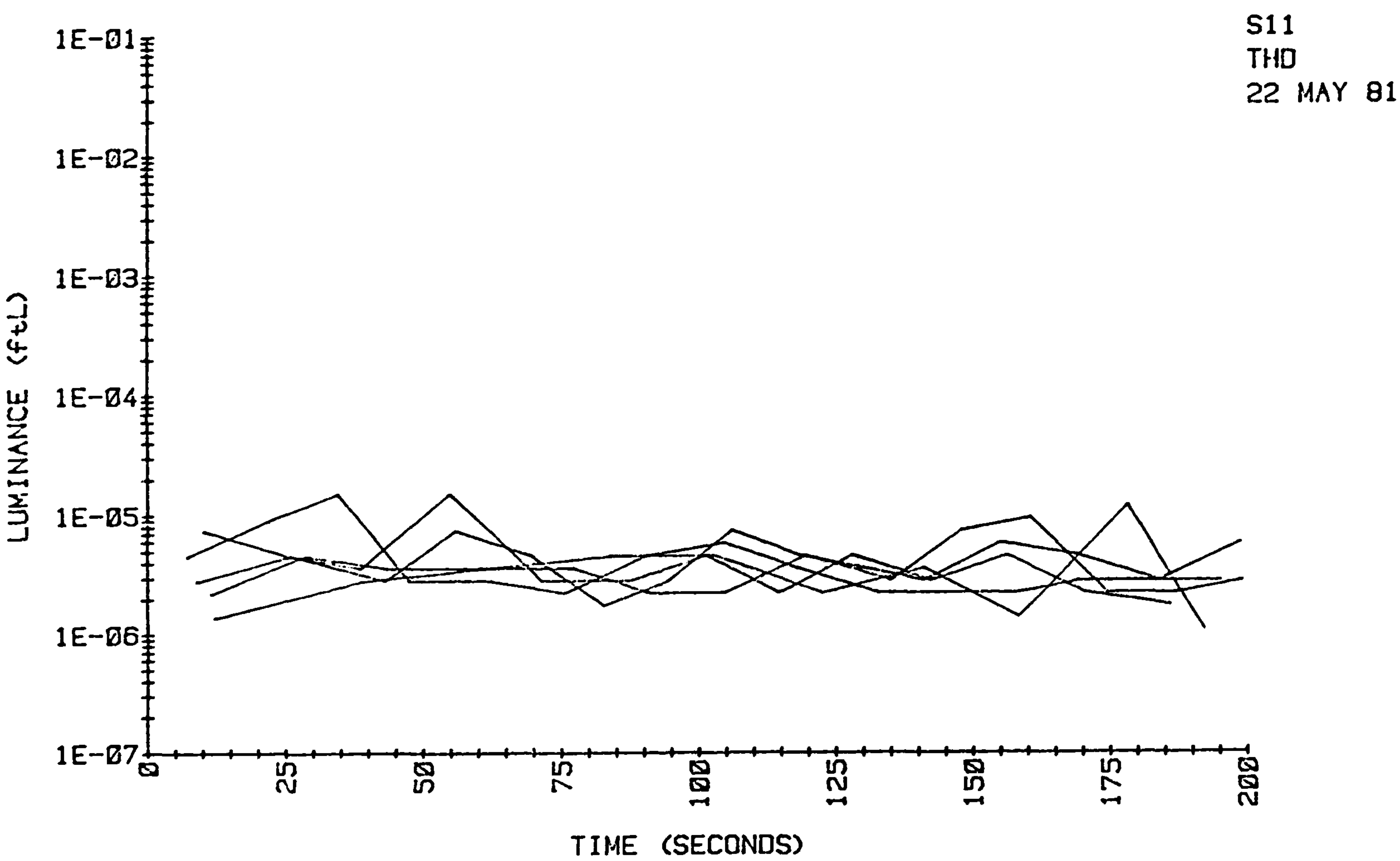
SPATIAL FREQUENCY (CPD)
SQUARE WAVE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THD
22 MAY 81
LUMINANCE (ftL)
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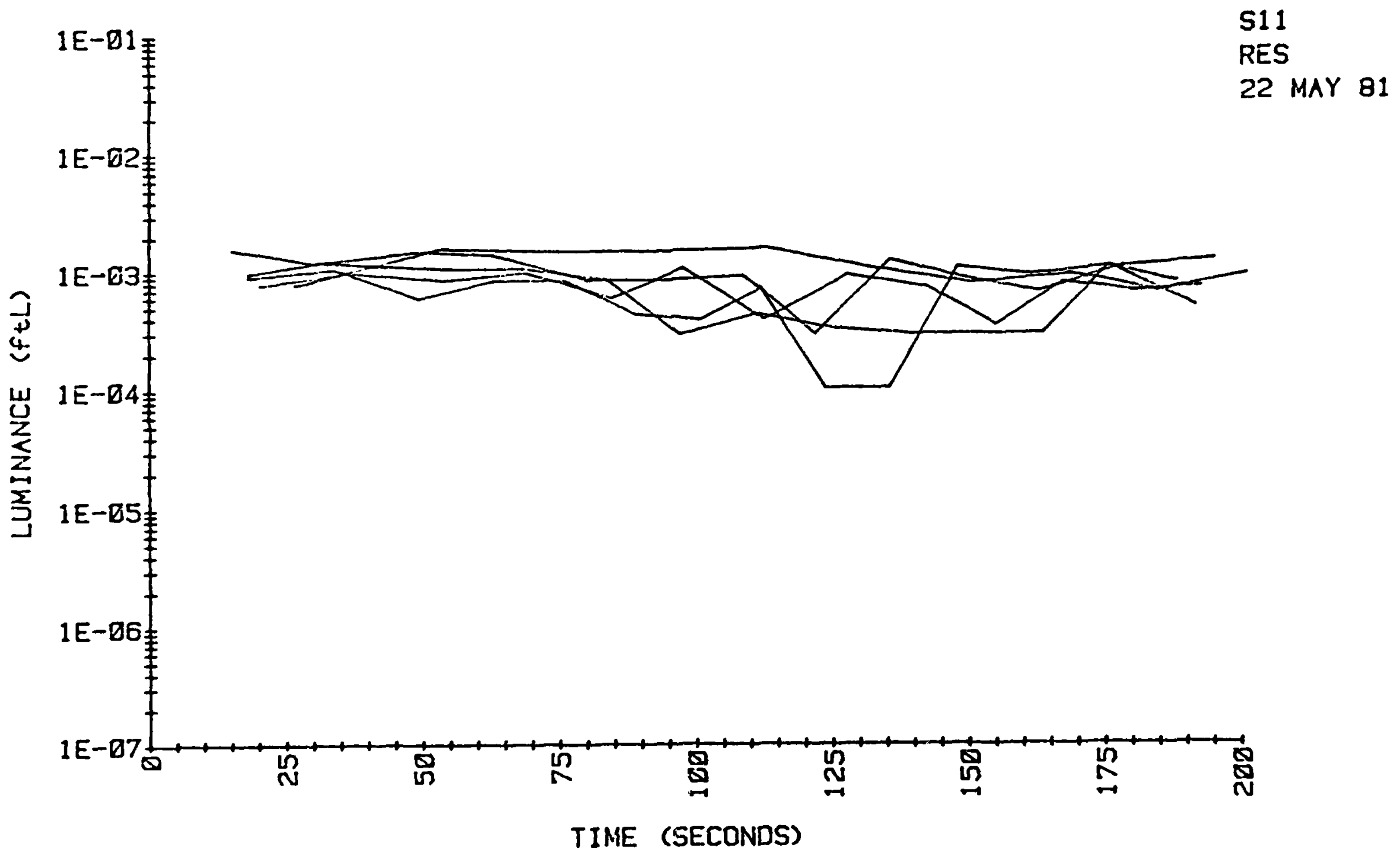
TIME (SECONDS)


S11
RES
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LUMINANCE (ftL)
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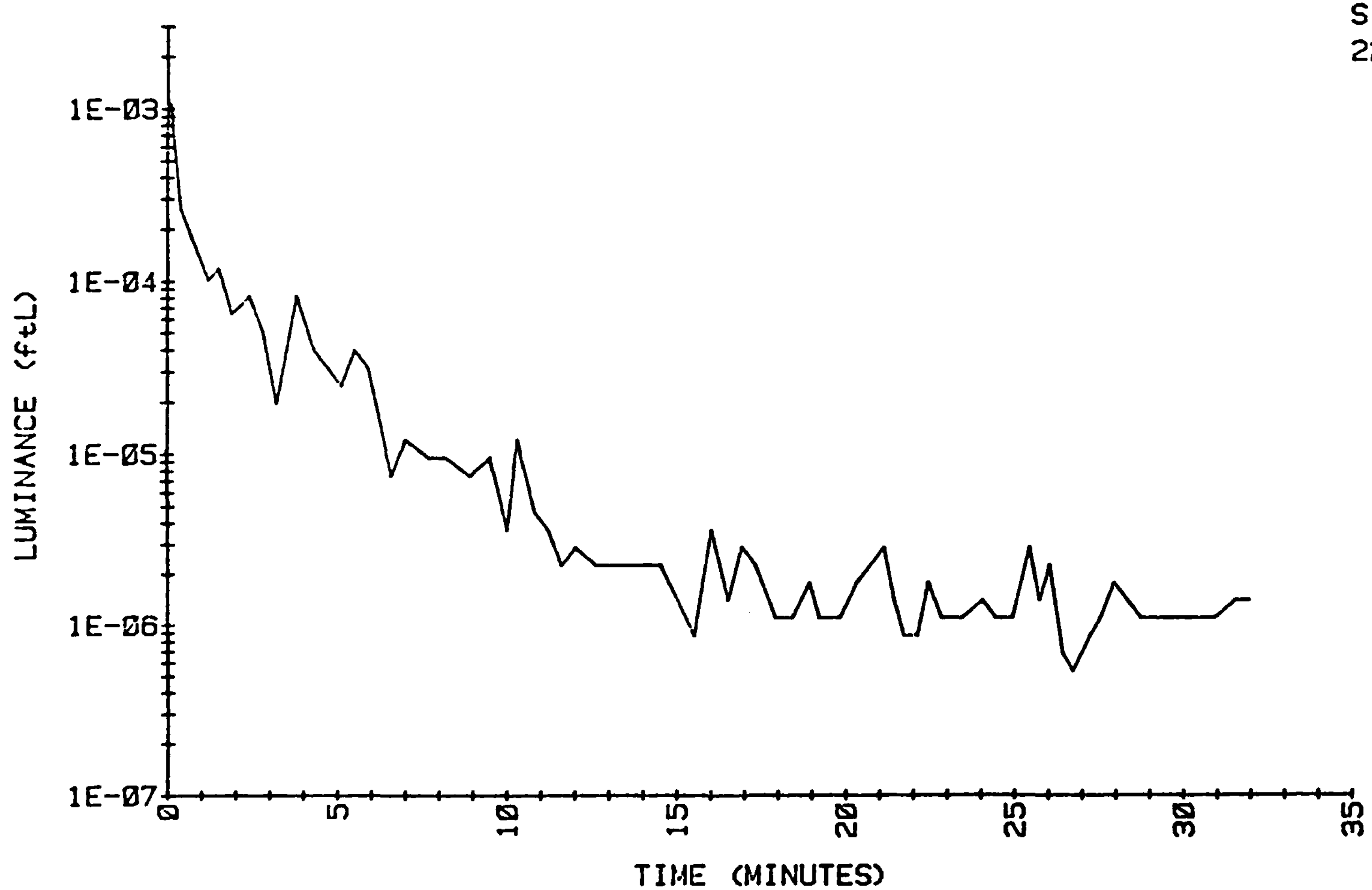
TIME (SECONDS)

S12
22 MAY 81



1E-03
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LUMINANCE (ftL)
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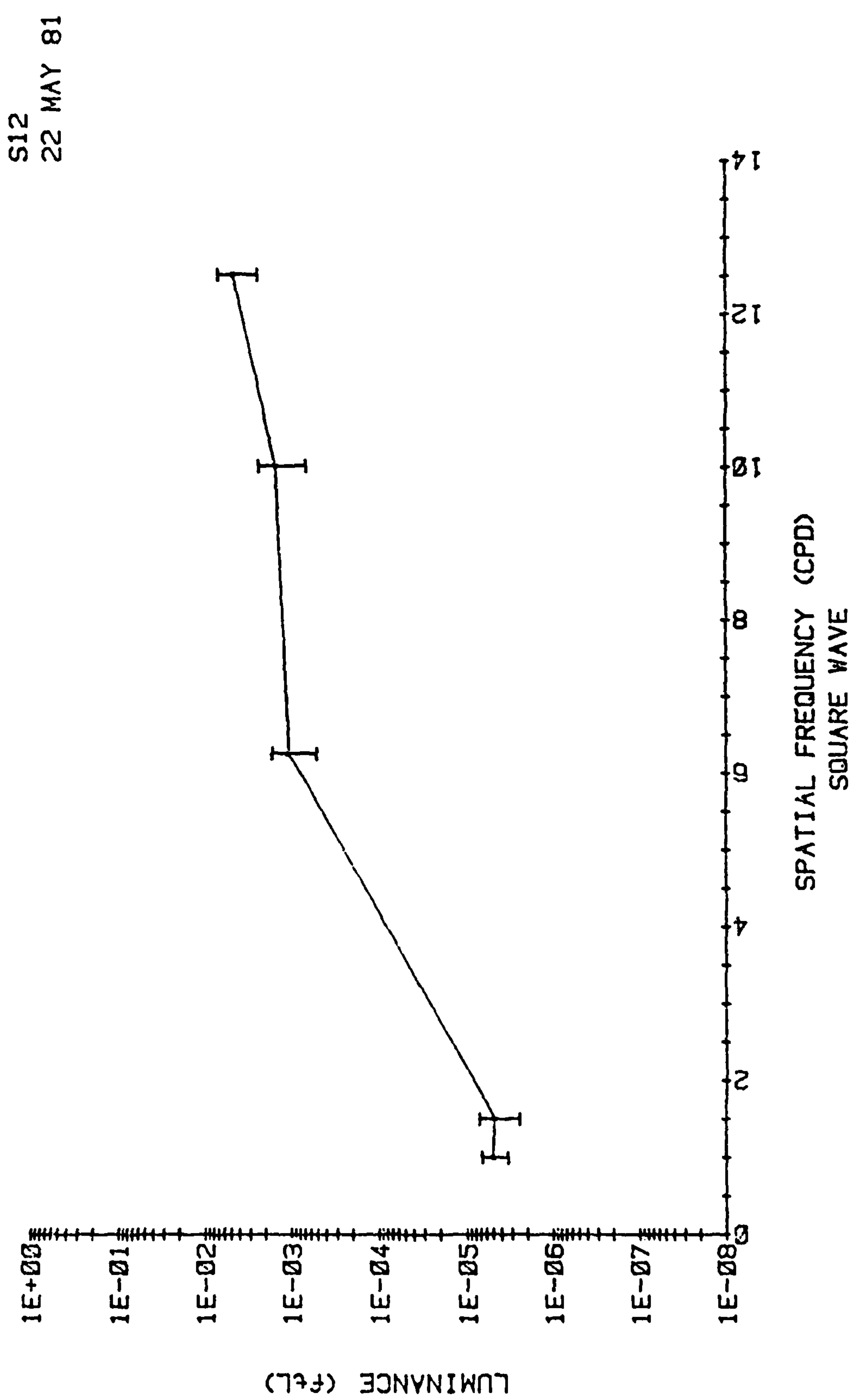
TIME (MINUTES)


S12
22 MAY 81
LUMINANCE (ftL)
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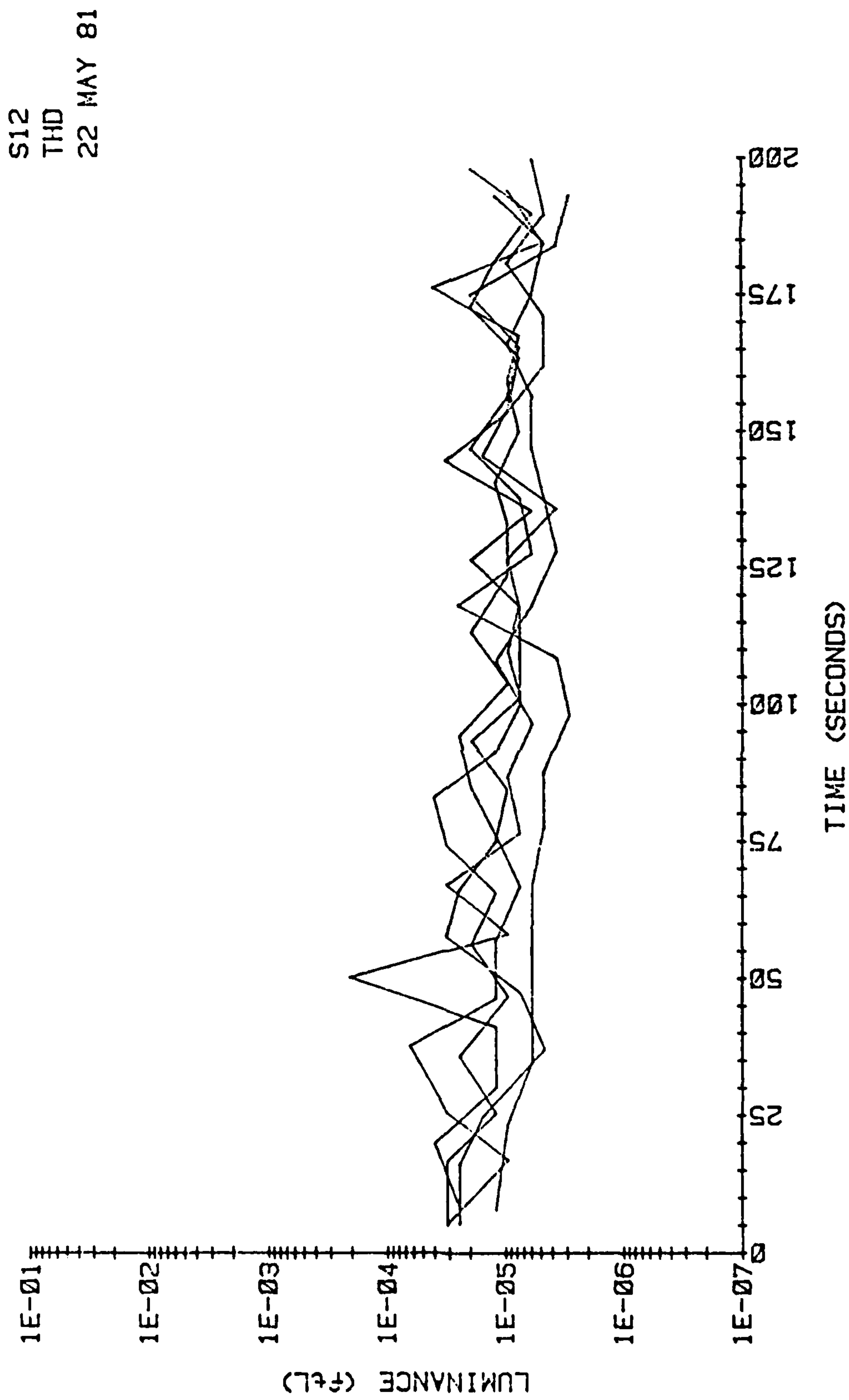
SPATIAL FREQUENCY (CPD)
SQUARE WAVE



S12
THD
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LUMINANCE (fL)
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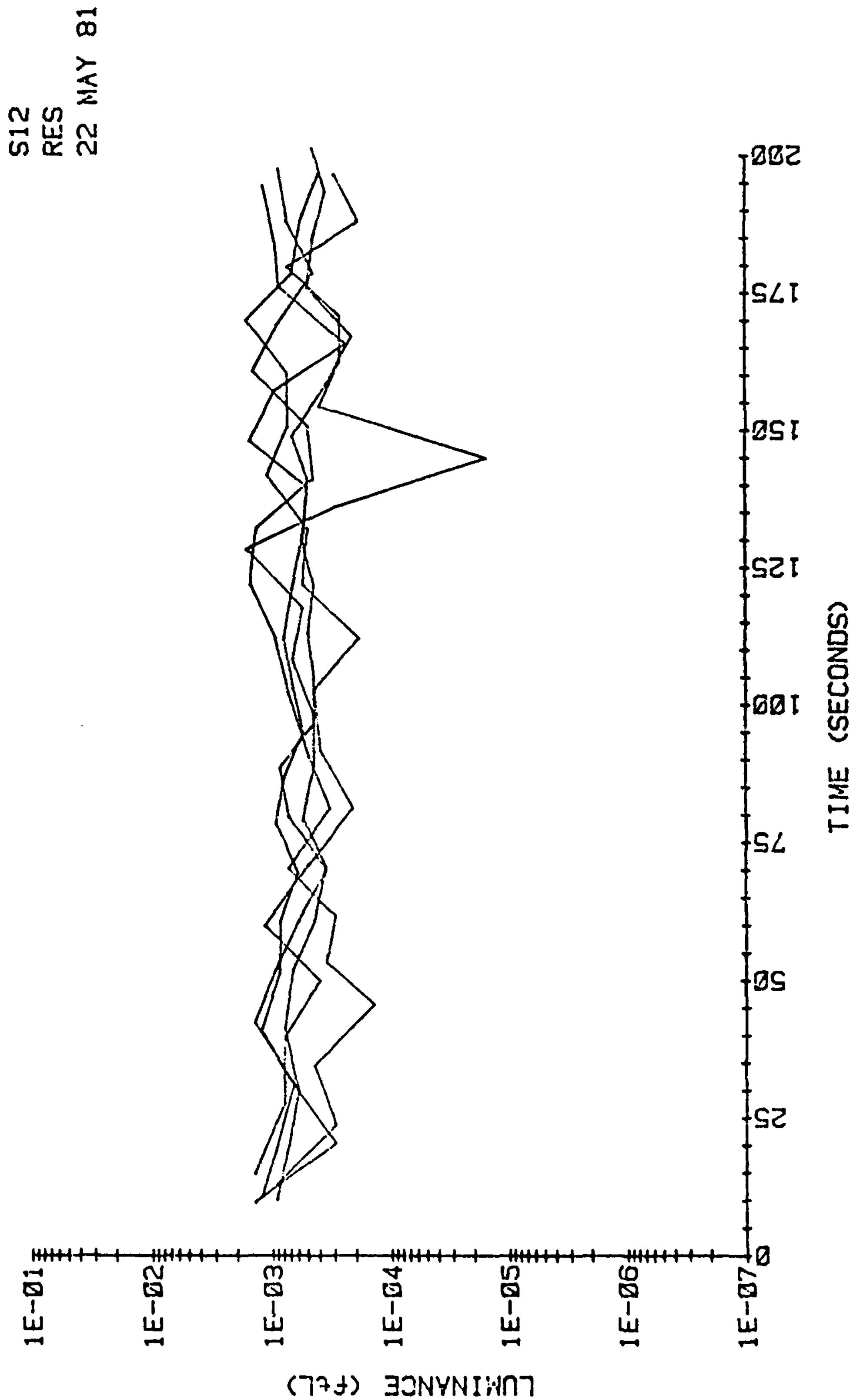
TIME (SECONDS)


S12
RES
22 MAY 81
LUMINANCE (f+L)
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1E-04
1E-05
1E-06
1E-07
TIME (SECONDS)
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175
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BIBLIOGRAPHY

1. Alpern, M. Effect of a bright light flash on dark adaptation of human rods. Nature. 2307. 394-396. 1971.

2. Arden, G.B. and Kolb, H. The effect of pressure blinding on dark adaptation. J. Physiol. 175. 39-40. 1964.

3. Arden, G.B. The importance of measuring contrast sensitivity in cases of visual disturbance. Br. J. Ophthalmal. 62:198-209. 1978.

4. Aspinall, P.A. A Two-filler method for dark adaptation study. Ophthalmologica. Vol. 169. Issue No. 4. 299-309. 1974.

5. Aubert, H. Studies in night vision. Ann. Physiol. Chem. 115:87. 1862.

6. Aulhorn, E. and Hamms, H. The Examination on Fitness for Driving at Darkness. Klinische Monatsblaetter fur Augenheilkunde. Vol 157 (6). 843-73. 1970.

7. Barris, M.C., Dawson, W.W., and Theiss, C.L. Human scotopic sensitivity increases on the day of ovulation. ARVO Abstracts. (Invest. Ophthalmol. Visual Sci. supp. 154. 1978).

8. Bartlett, N.R. and MacLeod, S. Effect of Flash and Field Luminance upon Human Reaction Time. J. Opt. Soc. Am. 44 (4):306-311. 1954.

9. Berson, E.L., Gouras, P., and Gunkel, R.D. Progressive Cone-rod degeneration. Arch. Ophthal. 80:68-76. 1968.

10. Berson, E.L. Experimental and therapeutic aspects of photic damage to the retina. Invest. Ophthalmol. 12:35-44. 1973.

11. Blakemore, C.B. and Rushton, W.A.H. Dark adaptation and increment threshold in a rod monochromat. J. Physiol. 181. 612-628. 1965.

12. Bowmaker, J.K., Dartnall, H.J.A. Visual Pigments of Rods and Cones in a Human Retina. J. Physiol. 298:501-11. 1980.

13. Brown, J.L., Graham, C.H. and Ranken, H.B. Luminance Thresholds for the Resolution of Visual Detail During Dark Adaptation. J. Opt. Soc. of Am. 43:197-202. 1953.

14. Brown, L.J., Kirschenstedi, A. and Shupp, F. Contributions of Rods and Cones to Visual Thresholds During Dark Adaptation. Technical Report AD-767040. Office of Naval Research. 1960.

15. Burg, A. Light Sensitivity as Related to Age and Sex. Perceptual and Motor Skills. 24:1279-1288. 1967.

16. Burian, H.M. and Hansen. W.W. 'An Automatic Self Registering Apparatus for the Recording of Global Dark Adaptation Thresholds'. Documenta. Ophthal. Vol. 26. 279-285. 1969.

17. Calissendorff, B. Effects of Repeated Smoking on Dark Adaptation. ACTA Ophthalmologia. Vol 55:261-268. 1977.

18. Connors, M.M. Effect of Wavelength and Bandwidth of Red Light on Recovery of Dark Adaptation. J. of the Optical Soc. of America. 56(1):111-115. Jan. 1966.

19. Craik, K.J.W. and Vernon, M.D. The nature of dark adaptation. Brit. J. Psych. 32:62-81. 1941.

20. Crosley, J.K. Potential initial aviator vision standardization among ASCC member nations, A discussion paper. U.S. Army Aeromedical Research Laboratory. Fort Rucker, Alabama.

21. Davidson, B., Echols, C., and Jose, R. The development of the Generation 11 as an aid for patients with Retinitis Pigmentosa and night blindness. Journal of Optometry and Physiological Optics. Vol. 53. No. 2. 88-94. Feb. 1976.

22. Dille, J.R., Booze, C.F. The 1975 Accident Experience of Civilian Pilots with Static Physical Defects. FAA-AM-77-20.

23. Dille, J.R. and Booze, C.F. The Prevalence of Visual Deficiencies Among 1979 General Aviation Accident Airmen. Aerospace Medical Association. Annual Scientific Meeting. 1981.

24. Dowling, J.E. Chemistry of Visual Adaptation in the Rat. Nature. 188:114-118. 1960.

25. Dyster-Aas, K., Krakau, T., Ohman, R. A simple device for testing night vision. Lakartidningen. Vol. 72. No. 24. 2619-20. June 1975.

26. El Hag, T.A., El Sheyati, M.F., Mekawi, M.F., Eid, S.Z. Comparative Study of the Dark Adaptation Time in the Normal Egyptians. Bull. Ophth. Soc. Egypt. Vol 69(73):647-652. 1976.

27. Feldman, J.B. Light threshold, its clinical evaluation. Arch. Ophthalmal. 26:466-471. 1941.

28. Ferguson, H.H. and McKellar, T.P.H. The influence of chromatic light stimulation on the subsequent rate of perception under conditions of low illumination. Brit. J. Psychol. 34. 81-88. 1944.

29. Florip, D.J. and Bauer, R.W. Dark adaptation Recovery after Pulsed Light. Ergonomics. Vol 16. No 6. 759-764. 1973.

30. Fujimura, K., Tsuchida, Y., Morita, Y., and Jacobson, J.H. Application of visually evoked response near the threshold of vision to objective measurement of dark adaptation. Am. Journal of Ophthalmology. Vol 79. No 1:141-150. 1975.

31. Fujimura, K., Tsuchida, Y., and Morita, Y. Application of Scotopic Visually Evoked Responses to Objective Measurement of Dark Adaptation. Acta Soc. Opthalmol. Jap. 77(9):1161-7. 1973.

32. Ginsburg, A.P. Specifying Relevant Spatial Information for Image Evaluation and Display Design: An explanation of how we see certain objects. Proceedings of the SID. Vol 21/3. 1980.

33. Goodson, R.A. Refractive Error Changes in Air Force Academy Cadets. Aerospace Medical Association. Annual Scientific Meeting. 1981.

34. Gunkel, R.D., Bornschein, H. Automatic Intensity Control in testing Dark Adaptation. Arch. Ophthalmol. 57:681-686. 1957.

35. Halperin, M.H., McFarland, R.A., Niven, J.I., and Roughton, F.J. The Time Course of the Effects of Carbon Monoxide on Visual Thresholds. J. Physiol. (Lond) 146:583-93. 1959.

36. Halperin, M.H., Niven, J.I., McFarland, R.A., and Roughton, F.J. Variations in Visual Thresholds During Carbon Monoxide and Hypoxic Anoxia (abstract). Fed. Proc. American Physiol. Soc. 6:120-21.

37. Hara, T. Visual Field Changes in Mesopic and Scotopic Conditions using Friedmann Visual Field Analyser. Nippon Ganka Gakkai Zasshi. Vol 83(5). 380-5. May 1979.

38. Hecht, S., Haig, C. and Chase, A.M. The Influence of Light Adaptation on Subsequent Dark Adaptation of the Eye. J. Gen. Physiol. 20. 831-850. 1937.

39. Hecht, S., Haig, C., and Wald, G. The Dark Adaptation of Retinal Fields of Different Size and Location. J. Gen. Physiol. 19:321-327. 1935.

40. Hecht, S., Hendley, C.D., Frank, S.R. and Haig, C. Annoxia and Brightness Discrimination. J. Gen. Physiol. 29:335-351. 1946.

41. Hecht, S., and Hsia, Y. Dark Adaptation Following Light Adaptation to Red and White Lights. J. Opt. Soc. of Am. 35. 261. (1945).

42. Hecht, S. and Mandelbaum, J. The Relation Between Vitamin A and Dark Adaptation. J. Am. Med. Assoc. 112. 1910-1916. (1939).

43. Hecht, S. and Shlaer, S. An Adaptometer for Measuring Human Dark Adaptation. J. Opt. Soc. Am. Vol 28. 269-275. 1938.

44. Henson, D.B. and Allen, M.J. A New Dark Adaptometer. Am. J. Optom. Physiol. Opt. 54:641-644. 1977.

45. Henson, D.B. and Williams, D.E. Normative and Clinical Data with a New Type of Dark Adaptometer. Am. J. Optom. Physiol. Opt. Vol 56. 4. 267-71. 1979.

46. Hollins, M. and Alpern, M. Dark Adaptation and Visual Pigment Regeneration in Human Cones. J. Gen. Physiol. 62:430-447. 1973.

47. Hopkins Night Vision Test. Personnel Research Section. Technical Report AD499804. Dec. 1942.

48. Huber, C. and Adachi-Usami, E. Scotopic Visibility Curve in Man Obtained by the VER. Adv. Exp. Med. Biol. 24:189-198. 1972.

49. Hulburt, E.O. Time of Dark Adaptation After Stimulation by Various Brightnesses and Colors. J. of Opt. Soc. of Am. Vol. 41. 6.401-404. 1951.

50. Johnson, R.M., Hyman, A., Gade, P.A. Helicopter Electro-optical System Display Requirements: III The effects of CRT display size and luminance on Dark Adaptation of Helicopter Pilots. U.S. Army Research Institute for the Behavioral and Social Sciences. Technical Report 443. March 1980.

51. Jones, R.K. and Wilcott, I.T. Topographic Impairment of Night Vision Related to Exercise. Am. J. Ophthalmol. 84(6):868-871. 1977.

52. Kabayama, T., Tsuneoka, H., Fukuda, J., Narazaki, S. Standardised Night Visual Acuity Testing for Airline Pilots With a New Nyctometer. Jap. Clin. Ophth. 6. 1978.

53. Kinney, J.A.S., Sweeney, E.J., and Ryan, A.P. A New Night Vision Sensitivity Test. U.S. Armed Forces Med. J. 11:1020-29. 1960.

54. Klingaman, R.L. The Human Visual Evoked Cortical Potential and Dark Adaptation. Vision Res. 16:1471-1477. 1976.

55. Kobrick, J.L. Effects of Hypoxia on Peripheral Visual Response to Rapid Sustained Stimulation. J. Appl. Physiol. 37:75-79. 1974.

56. Kobrick, J.L. and Dusek, E.R. Effects of Hypoxia on Voluntary Response Time to Peripherally Located Visual Stimuli. J. Appl. Physiol. 29:444-48. 1970.

57. Kojima, M., Zrenner, E. Determination of Local Thresholds in the Visual Field by Recording the Scotopic Visually Evoked Cortical Potential in Man. Ophthal. Res. Vol 12(1):1-8. 1980.

58. Lemmon, V.W. and Geisinger,S. Reaction Time to Retinal Stimulation Under Light and Dark Adaptation. Am. J. Psychol. 48:140-142. 1936.

59. Luria, S.M. and McKay, C.L. Effects of Low Levels of Carbon Monoxide on Visions of Smokers and Nonsmokers. Archives of Environmental Health. Vol 34(1):38-44. Jan-Feb 1979.

60. Luria, S.M., Kinney, J.A.S., McKay, C.L., Paulson, H.M., Ryan, A.P. Effects of Aspirin and Dimenhydrinate on Visual Processes. Naval Medical Research and Development Command Research Work Unit. Report Number 866.

61. MacLeod, S. Flare Effectiveness Factors: A Guide to Improved Utilization For Visual Target Acquisition. AMRL-TR-73-46. Nov 1973.

62. McFarland, R.A. and Fisher, M.D. Alterations in Dark Adaptation as a Function of Age. J. Gerontol. 10:424-428. 1955.

63. McFarland, R.A. and Forbes, W.H. The Effects of Variations in the Concentration of Oxygen and of Glucose on Dark Adaptation. J. Gen. Physiol. 24:69-98. 1940.

64. McFarland, R.A. The Effects of Altitude on Pilot Performance. In Aviation and Space Medicine. B. Hannesdale and C.W. Sem-Jacobsen (Eds) Oslo, Unereersitetslorleget. 96-108. 1969.

65. McFarland, R.A. Human Factors in Air Transportation. McGraw-Hill. 222. 1946. N.Y.

66. McFarland, R.A. Low Level Exposure to Carbon Monoxide and Driving Performance. Arch. Environ. Health. 27:355-59. 1973.

67. McFarland, R.A., Evans, J.W. and Halperin, M.H. Ophthalmic Aspects of Acute Oxygen Deficiency. Archives of Ophthalmology. 26:886-913. 1941.

68. McFarland, R.A. and Evans, J.M. Alterations in Dark Adaptation Under Reduced Oxygen Tensions. Am. J. Physiol. 127:37. 1939.

69. McFarland, R.A., and Halperin, M.H. The Relation Between Foveal Visual Acuity and Illumination Under Reduced Oxygen Tension. J. Gen. Physiol. 23:613-30. 1940.

70. McFarland, R.A., Halperin, M.H., and Niven, J.I. Visual Thresholds as an Index of the Modification of the Effects of Anoxia by Glucose. Am. J. Physiol. 144:378-88. 1945.

71. McFarland, R.A., Roughton, F.J.W., Halperin, M.H. and Niven, J.I. The Effects of Carbon Monoxide and Altitude on Visual Thresholds. J. Aviat. Med. 15:381-394. 1944.

72. McGuinness, D. Away From a Unisex Psychology: Individual Differences in Visual Sensory and Perceptual Processors. Perception. Vol 5:279-94. 1976.

73. Mancht, H.G. The Problem of Night Vision. Fachliche Mitteilungen. Herausgeber Amt Fuer Wehrgeobhysik. No 172. 1-30. 1972.

74. Mote, F.A., Biggs, G.E. and Michels, K.M. The Reliability of Measurements of Human Dark Adaptation. J. Exptl. Psychol. 48. 69-74. 1954.

75. Mote, F.A. and Riopelle, A.J. Effect of Varying the Intensity and Duration of Pre-exposure Upon Subsequent Dark Adaptation in the Human Eye. J. Comp. Physiol. Psychol. 46:49-55. 1953.

76. Norden, A. and Stigmar, G. Measurement of Dark Adaptation in Vitamin A Deficiency by a New Quantitative Technique. ACTA Ophthalmologica. Vol 47:716-722. 1969.

77. Ortlepp, J., Heydenreich, A., Neupert, M., Schmautz, K.H. Normal Values in Relation to Age and Individual Variation of Dark Adaptation. Klin. Mbl. Augenheilk. Vol 162:68-74. Jan 1973.

78. Osterberg, G. Topography of the Layer of Rods and Cones in the Human Retina. ACTA Ophthal. 6. 1935.

79. Parker, J.A., Armdt, J., Hallett, P. and Orpin, E. A Scotopic Perimeter for the Evaluation of Night Blindness. Invest. Ophthalmol. Visual Sci. Vol. Supp. 131. 1977.

80. Patek, A.J., Haig, C. Effect of the Administration of Thyroid Extract and of α Dinitrophenol Upon Dark Adaptation. Proc. Soc. Exper. Biol. and Med. 46:180-182. 1941.

81. Polinsky, D.M. and Young, F.A. The Effect of Hue Durations on Adaptation to Darkness. J. Opt. Soc. Am. 46:118-121. 1956.

82. Prestrude, A.M. and Larson, Carl F. Comparison by Dark Adaptation of Visual Thresholds in White and Black Observers. Bulletin of the Psychomomic Society. Vol. 12(4):282. 1978.

83. Pugh, E.N. Rushton's Paradox: Rod Dark Adaptation After Flash Photolysis. J. Physiol. (Lond). Vol 248:413-31. 1975.

84. Pugh, E.N. Rhodopsin Flash Photolysis in Man. J. Physiol. 248:393-412. 1975.

85. Records, R.E. Physiology of the Human Eye and Visual System. Harper and Row. 1979.

86. Richards, O.W. Effects of Luminance and Contrast on Visual Acuity Ages 16 to 90 Years. Am. J. of Optom. Physiol. Opt. Vol 54:178-184. 1977.

87. Richards, O.W. Night Myopia at Night Automobile Luminances: Final Report. Am. J. of Opt. Physiol. Optics. Vol 55(7):469-470. 1978.

88. Richards, O.W. Night Myopia at Night Automobile Driving Luminances: American Journal of Optometry and Archives of the American Academy of Optometry. Vol 44(8):517-523. July 1967.

89. Riopelle, A.J. and Bevan, W., Jr., The Distribution of Scotopic Sensitivity in Human Vision. Am. J. Psychol. 66:73-80. 1953.

90. Ripple, P.H. A Simple Night Vision Test. Ophthalmology (Rochester) Vol 86(8):1508. Aug. 1979.

91. Robertson, G.W. and Yudkin, J. Effect of Age on Dark Adaptation. J. Physiol. 103:1-8. 1944.

92. Ronchi, L. and Cetica, M. Time changes of absolute Threshold Luminance Across a 2-hour lasting uninterrupted session. Atti Fond. G. Ronchi. Vol 27:935-938. 1972.

93. Rowland, W.M. and Sloan, L.L. The Relative Merits of Red and White Light of Low Intensity for Adapting the Eyes to Darkness. J. Opt. Soc. Am. 34:601-604. 1944.

94. Rushton, W.A.H. and Powell, D.S. The Early Phase of Dark Adaptation. Vision Res. 12:1083-1093. 1972.

95. Rushton, W.A.H. The Rod Dark Adaptation Curve Measured Above Cone Threshold. J. Physiol. (Lond) 181:641-44. Dec. 1965.

96. Rushton, W.A.H. Dark Adaptation and the Regeneration of Rhodopsin. J. Physiol. 156:166-78. 1961.

97. Rushton, W.A.H. and Powell, D.S. The Rhodopsin Content and the Visual Threshold of Human Rods. Vision Res. 12:1073-1081. 1972.

98. Scano, A., Menghetti, E. Night Vision Adaptation in Homogeneous Groups of Pilots of Multi-engined Aircraft and of Non-pilots. Riv. Med. Aeron. Sp. Vol 33(1):168-74. Jan-Mar 1970.

99. Schull, W.J., Goldsmith, I., Clench, J., Ferrell, R.E., Barton, S.A. and Rothhammer, F. 2, 3-Diphosphoglycerate and Night Vision. Aviat. Space Environ. Med. 52(1):41-44. 1981.

100. Sexton, M., Malone, F. and Farnsworth, D. The Effect of Ultra-violet Radiation From Fluorescent Lights on Dark Adaptation and Visual Acuity. MRL No 169. Vol 9. 301-317. 1950.

101. Sheard, C. Dark Adaptation, Some Physical, Physiological, Clinical and Aeromedical Considerations. J. Opt. Soc. Am. 34:464-508. 1944.

102. Sloan, L.L. The Threshold Gradients of the Rods and the Cones in the Dark-Adapted and in the Partially Light-Adapted Eye. Am. J. Ophthalmol. 33(7):1077-1089. 1950.

103. Sloan, L.L. Rate of Dark Adaptation and Regional Threshold Gradient of the Dark Adapted Eye: Physiologic and Clinical Studies. Am. J. Ophthalmol. 30:705-720. 1947.

104. Smith, S.W., Morris, A. and Dimmick, J.I. Effects of Exposure to Various Red Lights upon Subsequent Dark Adaptation Measured by the Method of Constant Stimuli. J. Opt. Soc. Am. 45:502. 1955.

105. Stabell, B. Rods as Color Receptors in Scotopic Vision. Scand. J. Psychol. 8:132-138. 1967.

106. Stabell, B. and Stabell, U. Color Threshold Measurements in Scotopic Vision 1. Pre-stimulation Varied. Scand. J. Psychol. 8:268-272. 1967.

107. Stabell, U. and Stabell, B. Rods as Color Receptors. Scand. J. Psychol. 6:195-200. 1965.

108. Stabell, U. and Stabell, B. Colour Threshold Measurements in Scotopic Vision. Scand. J. Psychol. Vol 9(2):133-7.1968.

109. Sullivan, G.D. and Georgeson, M.A. The Missing Fundamental Illusion: Variation of Spatio-Temperal Characteristics with Dark Adaptation. Vision Res. Vol 17:977-981. 1977.

110. Thornton, S.P. A Rapid Test for Dark Adaptation. Ann. Ophthalmol. 9(6):731-4. June 1977.

111. Troemel, R.G. Dark Adaptation as a Function of Caffeine and Nicotine Administration. Proc. S.D. Acad. Sci. Vol 30:79-84. 1951.

112. Wald, J. Vitamin A in Eye Tissues. J. Gen. Physiol. 18:905-912. 1934.

113. Wald, C.J. Analysis of Retinal Function by a Two Filter Method. J. Opt. Soc. Am. 50:633-641. 1960.

114. Wald, G., Harper, P.V., Goodman, H.C. and Krieger, H.P. Respiratory Effects Upon The Visual Threshold. J. Gen. Physiol. Vol 25:891-903. 1942.

115. Weale, R.A. High Light Intensities and Photo-chemical Reactions of Human Visual Pigments in Situ. Quant. Biol. 30:335-343. 1965.

116. Welsh, K.W., Vaughan, J.A., Rasmussen, P.G. Survey of Cockpit Visual Problems of Senior Pilots. Civil Aeromedical Institute. FAA-AM-77-2.

117. Wilson, A.J. and Seller, S.E. Reaction Time to Scotopic Flashes of Light. Am. J. Optom. Physiol. Opt. Vol 54(12):845-8. 1977.

118. Wolf, E. Effects of Exposure to Ultra-violet Light on Human Dark Adaptation. Proc. Nat. Acad. Sci. 32:219-226. 1946.

119. Wolf, E., Zigler, M.J. and Solomons, H.B. Variability of Dark Adaptation. J. Opt. Soc. Amer. 50:961-965. 1960.

120. Zuege, P. and Drance, S.M. Studies of Dark Adaptation of Discrete Paracentral Retinal Areas. Canad. J. Ophthal. 2:35-40. 1967.

121. Zwick, H., Biggs, S.L., O'Mara, P.A. and Van Sice, C.W. A Solid State Dark Adaptometer (U). Letterman Army Institute of Research. San Francisco, California.

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